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DESCRIPTION OF COOS BAY, OREGON, AND THE IMPROVEMENT OF ITS ENTRANCE BY THE GOVERNMENT.

BY

WILLIAM W. HARTS, M. Am. Soc. C. E.

WITH DISCUSSION BY

ESSRS. LEWIS M. HAUPT, W. M. BLACK, H. C. RIPLEY, C. H.
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No. 910.

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By William W. Harts, M. Am. Soc. C. E.

Presented May 15th, 1901.

WITH DISCUSSION.

The recent completion of the north jetty at Coos Bay, Ore., and the satisfactory results following its construction make it appear of value to give some description of this work and the conditions of the entrance prior to the commencement of operations, especially as a study of certain methods of construction, satisfactorily used here and in neighboring localities, may be found of some value in designing works at other similar places.

Coast.—The Pacific Coast, north of San Francisco, embracing more than 800 miles, is not abundantly supplied by nature with suitable harbors. The Puget Sound ports and the mouth of the Columbia River on the north and San Francisco Bay on the south are the principal harbors available for deep-draft and ocean-going ships, and the entire coast line has few other harbors which are susceptible of improvement, at a reasonable cost, to the extent of making them suitable for more than moderate-draft vessels.

This part of the coast is remarkable for its boldness and continuity. From Port Orford, near the California State line, north to the Columbia River, the coast is a continuous, almost unbroken, line, but, even so, consists of a succession of bold headlands and sandy reaches, broken by but few bays or rivers. The bights between the headlands are filled out with bare sand reaches, usually without vegetable life of any kind, and frequently rising in dunes of considerable height. The action of the elements in wearing away the headlands seems to be also directed toward filling out the coast lying between them, so that a nearly continuous shore line is maintained.

The Coast Range of mountains lies close to the line of the coast, and the headlands appear to be portions of these mountains not equally worn away by the agencies which have eroded the remainder. These mountains are mostly soft, metamorphic sandstone of the tertiary age, and are believed to overlie granite, from the outcrop at Point Reyes, In passing up the coast, basalt is encountered at Cape Foulweather, presumably overlying this sandstone formation. These sandstone headlands have supplied, by their disintegration and by the erosion by wind and sea, an abundance of fine, loose sand which is found in great quantities everywhere along the coast from Cape Blanco to the Columbia River, and even to Puget Sound. The action of the sea waves and tidal currents upon the sand of the ocean bottom near shore and the action of the wind above the water line is believed to have caused to a great degree the singular character of the bays and river entrances and the existence of the usual semi-circular or crescent-shaped bars across their openings into the ocean.

The severe action on the shore by the ocean waves during storms is increased by the sharp slope seaward of the ocean bottom and by the lack of other land for thousands of miles to the westward and southward to break the force of the seas. From the Columbia River to beyond Coos Bay the contour of 500 fathoms depth in the ocean is only about 30 miles off shore. Near Coos Bay the 50-fathom contour is only about 5 miles off shore, and the 1 700-fathom contour is only about 50 miles off shore.* Compared with many other coasts this slope seaward is very abrupt, permitting great depths to be found comparatively close in. This deep water near shore and the tremendous reach of the ocean to the westward and southward, whence come the worst storms of this region, are features that help to make this coast one of the most exposed in the world. The full force and violence of the waves is therefore directed against or along this shore, uninterrupted by shoal water, and transmitted probably for hundreds of miles in the open sea.

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* U. S. Coast, and Geological Surveys.

Thomas Stevenson, the English harbor engineer, has even expressed in a formula the relation between the height and force of waves and the distance of exposure in miles ($h = 1.5 \sqrt{d}$).

Storms.—It was thought for a long time that no harbor works, along this part of the Pacific Coast, extending into the open sea, unless unduly expensive, could withstand the force of these waves, and for this reason improvements at certain harbors were formerly attempted by constructing deflecting jetties inside the entrances, where they were more or less protected, in the hope that this work would better the channels across the bars without extending the construction beyond the general line of the shore. These works, unfortunately, were only partially successful.

The worst storms along this part of the Pacific Coast seldom make a lee shore, but come from the south and southwest, thus enfilading the coast. They usually start in the south or southeast and shift to the westward until they reach a quarter almost due southwest. In the winter the storms are occasionally very severe and often of long duration, and at this season almost invariably blow hardest and longest from the southwest. In the summer, on the other hand, the wind is generally northwest, and the summer gales come usually from that quarter. These storms and winds often set up a very noticeable off-shore current, said to amount at times to 2 knots, which, accordingly, is northward in the winter and southward in the summer, being more marked and of longer duration to the northward. At certain localities the conformation of the shore line induces eddy currents, opposite in direction and closer in shore.

As to the exposure of this portion of the Pacific Coast, the testimony of experienced navigators, in 1881, before a Board of Engineer Officers convened to report on a site for a harbor of refuge on the Pacific Coast, went to indicate that there were few localities in the world where the seas were worse during storms. On the California Coast these dangerous storms are less violent, less frequent and shorter than on the Oregon and Washington Coasts, but north of California, especially from Cape Blanco to Cape Flattery, they are frequently very violent and sometimes succeed each other in rapid succession for weeks. Some navigators give Cape Foulweather, about 100 miles south of the Columbia River and 100 miles north of Coos Bay, as the locus of the worst storms. Captain Maury, Commander of the *City of Tokio*, stated to this Board:

"There is no such sea in the world except south of the two capes or in the Indian Ocean. I have seen the sea break in 8 to 10 fathoms. There is no comparison between the heaviness of the southwest sea on this (Pacific) coast and that which has damaged the works at Cherbourg and other places."

Captain Simpson stated:

"There may be such swells in other oceans, but I have never seen them."

Several other vessel captains testified that they had seen the waves on this coast break in 8 to 10 fathoms, and some said they had seen them break in 15 fathoms. Sometimes a heavy swell breaks on the shore in a dead calm, probably the result of a distant storm, the propagation of the waves of which is favored by the great depth of the sea.*

Harbors.—The character of the harbors on the Oregon and Washington Coasts is noticeably similar. In almost every case the entrance from the sea is between a high, bold headland on the one side and a long, low-lying tongue of sand on the other. Sometimes this tongue lies to the northward of the opening, as at Coos Bay, and sometimes to the southward, as at Tillamook and Yaquina Bays and the mouth of the Columbia River. In all cases at some distance out from the opening is to be found a crescent-shaped bar, more or less continuous, and usually completely encircling the entrance. These bars, from their insufficient depths, form the principal obstructions to these harbors, and on account, also, of the shoal water on these bars, the waves during storms often break entirely across the entrances, making the crossing in or out by vessels very hazardous, even when depths are sufficient; or, if the seas are not actually breaking, the water becomes so rough that crossing is unsafe. In such cases ships are "bar bound," with ample depths on the bar. The improvement of these harbors, therefore, usually contemplates the formation of a deep channel through the bar in some selected place.

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* See Annual Report, Chief of Engineers, 1881.

Bar Formation.—The main causes of the formation of these bars seem plain. The ocean bottom along the shore for some distance seaward is composed of fine sand which is easily moved. The waves of the westerly and southwesterly storms, in breaking off-shore, dislodge great quantities of this sand and carry it shoreward to be piled on the beaches or deposited by the waves and littoral currents in any exposed openings. Oftentimes small creeks are completely closed in this way. In these cases the damming effect of this sand thus piled up goes on until the quantity and difference of head of water inside the bar and outside is sufficient to cut a new channel.

In the mouths of large bays the action is similar, the shoaling continuing most actively during the storms; erosion, however, to a greater or less extent, taking place afterward by the scour, due to the water passing in and out of the bay on the tides. Unquestionably, much sand is also carried into the bays on the flood tides, and large quantities of this sand are then deposited in sheltered places within the bay; but large quantities are also carried back into the ocean on the ebb, the well-known tendency of the channels in tidal estuaries and bays, to maintain their depths or even deepen them, being usually sufficient to prevent any deposit in the path of the currents themselves.

The channels, in reaching the ocean, are also sometimes crowded far to the northward, as at Tillamook Bay, by the encroachment of the moving sand, due to the southwesterly storms and shore currents, until the distance the water is compelled to traverse in getting out of the bay on an ebb tide is enough to create a hydraulic head nearer the old entrance sufficient to cause a new exit to be cut out. In some cases, as at the mouth of the Nehalem River, the channel is crowded to the southward in a similar manner by the building up of the spit on the north side of the entrance. The direction taken by the free end of these sand spits, as a general thing, indicates the direction of the resultant sand movement at that locality.

This bar-forming action during storms has been observed at Coos Bay, where the action of the waves in stirring up the sand of the sea bottom was plainly visible in the discolored waters off-shore, and where, on one occasion, during a severe storm, the bar shoaled 4 ft. in a single flood tide and scoured out again on the next ebb. Again, at Coos Bay, during a long-continued period of southwesterly storms, in November, 1899, the channel over the bar shoaled to 9 ft., but on the cessation of the storms during the next month the scouring effect of the tides soon removed this shoal down to the former depth. At the Siuslaw River, the entrance is continually being forced northward, in all for a distance of over a mile, by the constant movement of the sand. This action continues during, perhaps, several seasons, until the channel finally breaks through the bar thus formed, opening a new exit farther to the southward, which again passes through a similar cycle.

It thus appears that at all these harbors there are two main forces constantly at work, one, the effect of the waves, usually in westerly storms, and of the local littoral currents, to fill up or shoal the entrances to the rivers and bays, and the other, the scouring effect of the tides passing in and out, tending to keep the entrances open. If there were no tidal action, the openings into the bays would probably close more or less completely, depending on the amount of fresh water passing out, and if there were no shoaling action of the sea and shore currents, the tidal scour would be likely to maintain entrances of ample depths. The extent of this tidal action, of course, is limited, and its location and amount are governed very largely by such features as the extent of the tidal prism within the bay, the shape of the harbor throat or entrance and the existence of littoral currents in the ocean outside. On an ebb tide the volume of water passing out through the harbor throat, where the width is naturally contracted, has a bottom velocity usually enough to scour and maintain considerable depths. At Coos Bay these depths are in places as much as 60 ft. in the harbor throat, and the surface velocities observed are often as much as 4½ miles per hour. When this tidal stream, however, is free to change direction and diverge on emerging into the ocean the consequent changes of direction, the meeting with outside currents, or the absorption of the energy of the moving water by the ocean, reduces the velocity and widens its area of application over the entire crest of the bar, so that the scouring and transporting effect of the water is thus dissipated. When the velocities of the ebb tide are reduced in the ocean so as no longer to pick up and move outward the particles of sand composing the bottom, the bar is no longer eroded. This, in a certain measure, explains the usual crescentic shape of most of these bars.

It may, therefore, be broadly stated that the bars lying in front of the Pacific Coast harbors are apparently mainly caused by the resultant action of the sea on the one hand and that of the tides on the other, while, in all cases, the deposit of silt or other matter in suspension brought down by fresh-water currents, as at the mouth of the Mississippi, is a means of building up a bar that appears to be of no special importance in this region.

Improvement.—This diagnosis of the difficulty suggests the remedy. As the forces going to build up the bars are intermittent, but constantly recurring, no temporary expedient, such as dredging, would be of any special value, owing to the extreme likelihood of such work being completely nullified by the effect of a single severe storm. Any improvement, to be valuable, must, therefore, affect the causes which make the bar, and control the other natural forces constantly at work, so as to maintain the desired depths. If works can be devised to prevent the encroachment of the sand on the channel and at the same time prevent the divergence and dissipation of the effect of the ebb tides, by confining and directing these tidal currents at a selected point of the bar, improvement may be confidently expected.

The method of accomplishing this by jetties was first commenced on the Pacific Coast in 1881, at Yaquina Bay, lying on the Oregon Coast, about 88 miles north of Coos Bay. Here, the entrance to the bay in its original condition was obstructed by the usual enveloping bar on which the best depths, the greater part of the time, were only 7 ft. at mean lower low water. The best depths were found usually in a north channel and in a south channel, both sharply skirting the shore in opposite directions before turning seaward. Occasionally, depths even better than this were found, but they invariably relapsed into their usual condition.

The construction of a single south jetty was determined on first, to close the south channel and direct this volume of water over the bar at such a point as to produce a new entrance along a line nearly due west. This location was chosen partly with a view to make it easier for vessels in passing in and out. The construction of the south jetty seemed sufficient to shut off the supply of moving sand, borne northward along the coast by the currents and by racing waves in storms, but did not give the requisite amount of contraction and direction to the ebb tide, as much water escaped through the old north channel which it was later found necessary to close before much improvement on the bar resulted.

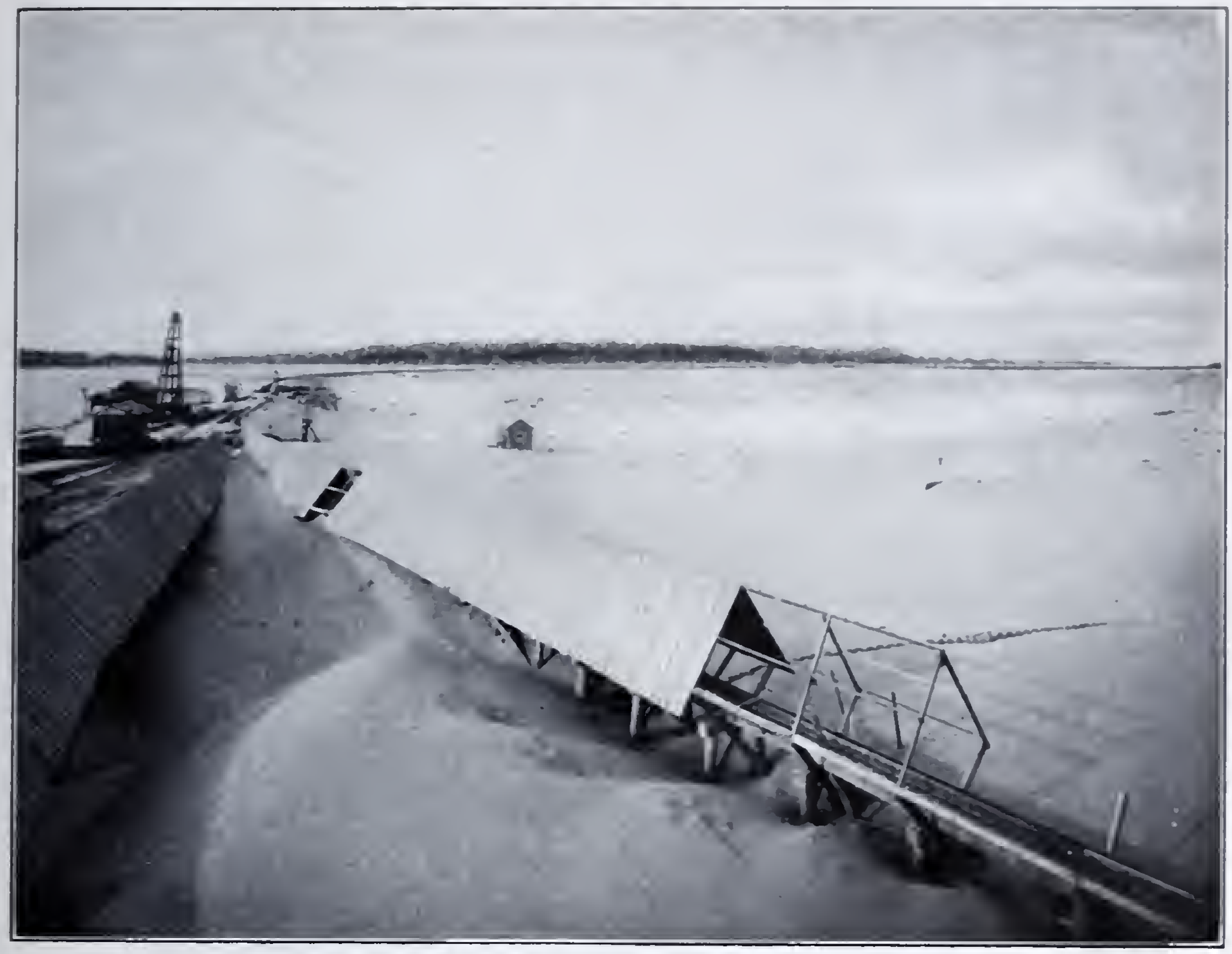


FIG. 1.—GENERAL VIEW OF JETTY. COOS BAY. ORE.

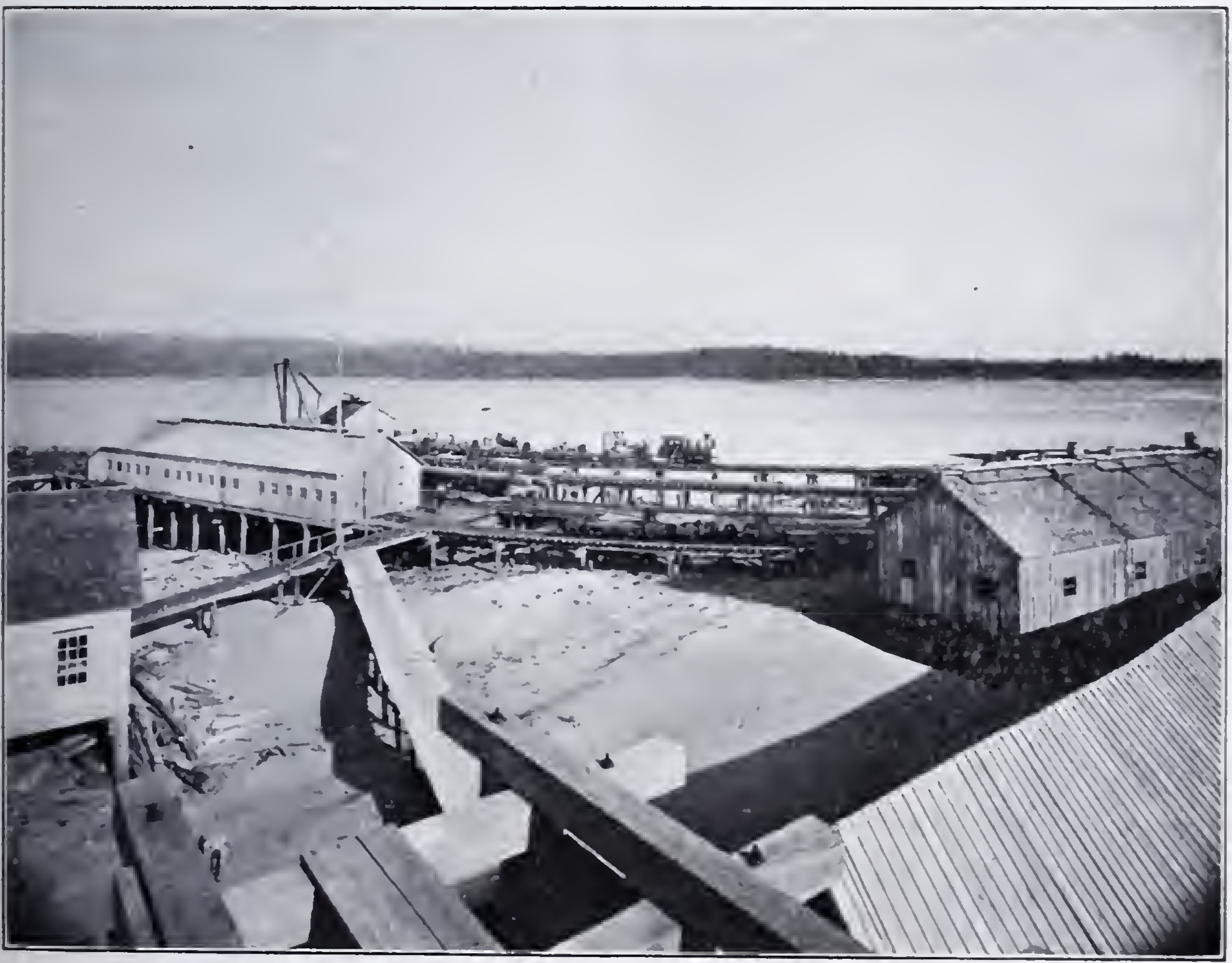


FIG. 2.—GENERAL VIEW OF LOADING WHARF, COOS BAY, ORE.

It was stated before commencing work that the improved depth that could be expected would be at least 10 ft. at mean lower low water, or 17 ft. at mean high tide. After the completion of the south jetty, but long before the completion of the north jetty in 1896, a channel straight out to sea having a least depth of 14 to 15 ft. at mean lower low water, or 21 to 22 ft. at high tide (the mean tidal rise above mean lower low water at this harbor being 7.1 ft.), was produced by the jetties, which depths have been maintained ever since, with the exception of a short period in the spring of 1899, when temporary shoaling of about 2 ft. was reported.

These jetties were the pioneers of the Pacific Coast harbor works. Here, for the first time on this coast, rip-rap jetties were extended out into the open sea. Even in the manner of construction, the jetties at Yaquina Bay developed the type found so useful elsewhere on this coast. At first, it was attempted to build the rock jetties from scows and lighters, as is done on places on the Atlantic and Gulf Coasts. The effect of the heavy seas encountered was too great. Likewise, the plan of using cribs was doomed to failure. The plan finally adopted, first used here in the United States, was the invention of J. S. Polhemus, M. Am. Soc. C. E., Assistant Engineer, in local charge of the work. It consisted in building a tramway from shore, 20 or more feet above the water, carrying double, narrow-gauge tracks, on which the stone for the enrockment was carried in small cars hauled by a locomotive. This tramway required the use of a pile-driver running on the tramway, overhanging far enough to drive the piles of the next bent beyond the existing end of the tramway.

At Yaquina Bay, also, the plan of building brush mattresses while they were suspended under the tramway, also the invention of Mr. Polhemus, was first adopted in the United States. The general methods of doing work which were originated here, although improved in many minor ways afterward, have never been far departed from in similar works on this coast. This work at Yaquina Bay has been eminently successful, from an engineering point of view.

The use of two jetties converging seaward, found so satisfactory at Yaquina Bay, has been influential in causing to be included, in the projects for the improvement of most of the Pacific Coast harbors now under this kind of improvement by the Government, the provision for second jetty, should a single one prove insufficient. At Humbolt

Bay, Cal., Yaquina Bay and Coquille River, Ore., two jetties have already been found necessary, while at Coos Bay and Columbia River, Ore., and Grays Harbor, Wash., the natural conditions are such that one jetty has already accomplished so much improvement that the necessity for the second jetty is not yet apparent.

There are good grounds for believing that a single jetty performs only a partial service, but at the Columbia River the rocky point at Cape Disappointment acts as a second natural jetty, and at Coos Bay this partial service performed by one jetty has been sufficient thus far, while at Grays Harbor the same favorable results are promised by a partial control of the ebb currents. The trace of the jetties, which side of the entrance to build from first, the length to which they should be extended, the distance apart at their outer ends, are all questions upon which local considerations have so much bearing that it does not seem possible to formulate any fixed rule for them. The questions for an engineering solution must also be affected by consideration for the needs of navigation; for the easy use of the improved channels by vessels is of prime importance.

Objections.—The supposed need of extending the jetties seaward from time to time, to meet the advancement of the foreshore caused by the jetties, is given by some as an objection to this plan of improvement. Such jetty extension has been found necessary already at the mouth of the Columbia River to maintain the improved depths, but nowhere else thus far on this coast. The sand collecting in the groin or angle between the jetty and shore causes at first, in nearly every case, a rapid advancement seaward of both the high- and low-water lines. This sand also backs up the jetty, usually rendering a very light rubble wall ample in strength for all purposes. The objection is made that on account of this action the jetties only transfer the original trouble to another place by pushing the shore lines and the bar farther seaward, as soon as the collected sand has filled the groins. This objection is not very well sustained by the evidence of the facts. While it may not be possible in every case to determine beforehand exactly the length of jetties necessary for the permanent improvement of a special locality, it appears only reasonable to believe that there is a length for each harbor on this coast beyond which it will not be necessary to extend them, the effect of the littoral currents

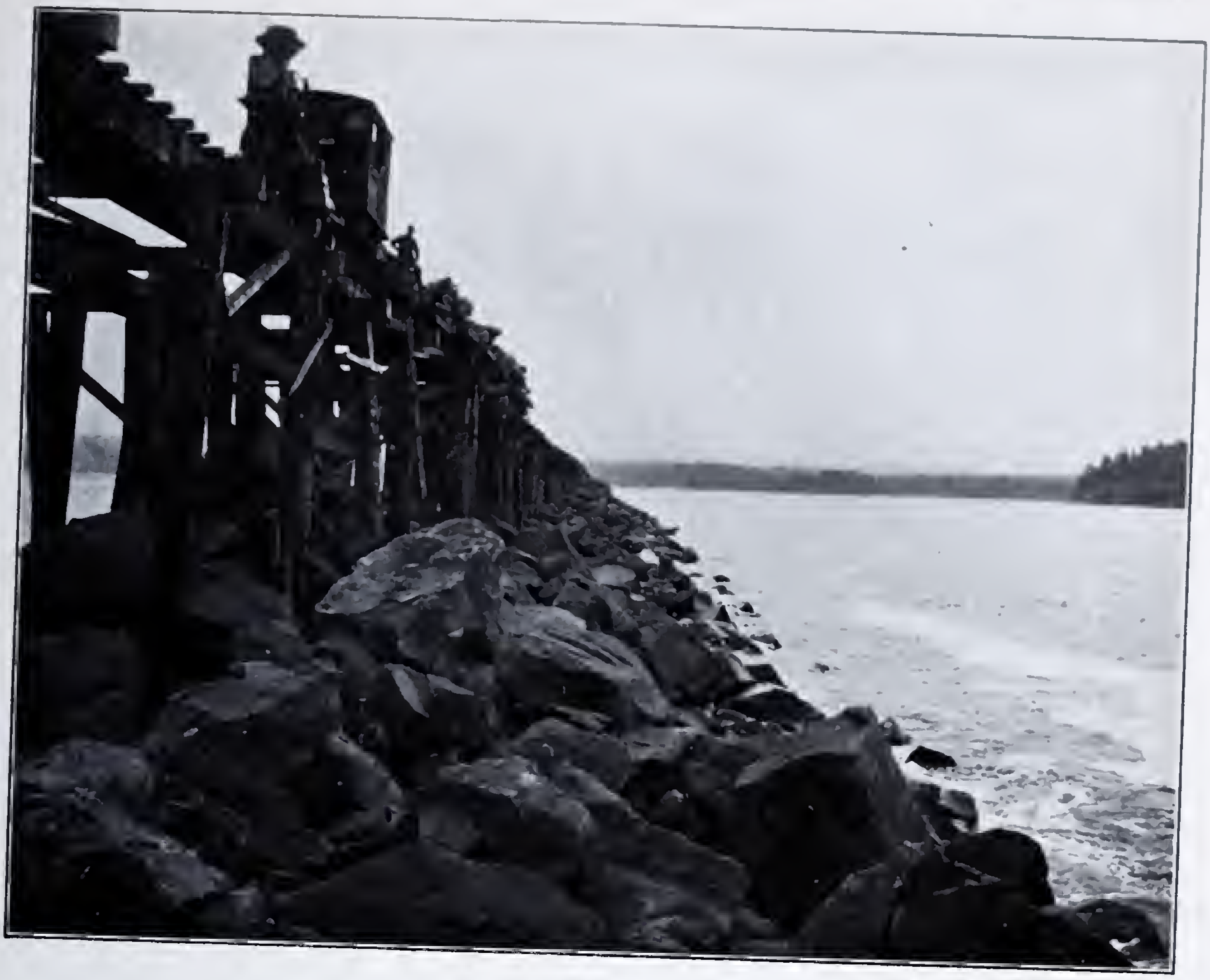


FIG. 1.—NEAR VIEW OF ENROCKMENT, COOS BAY JETTY.

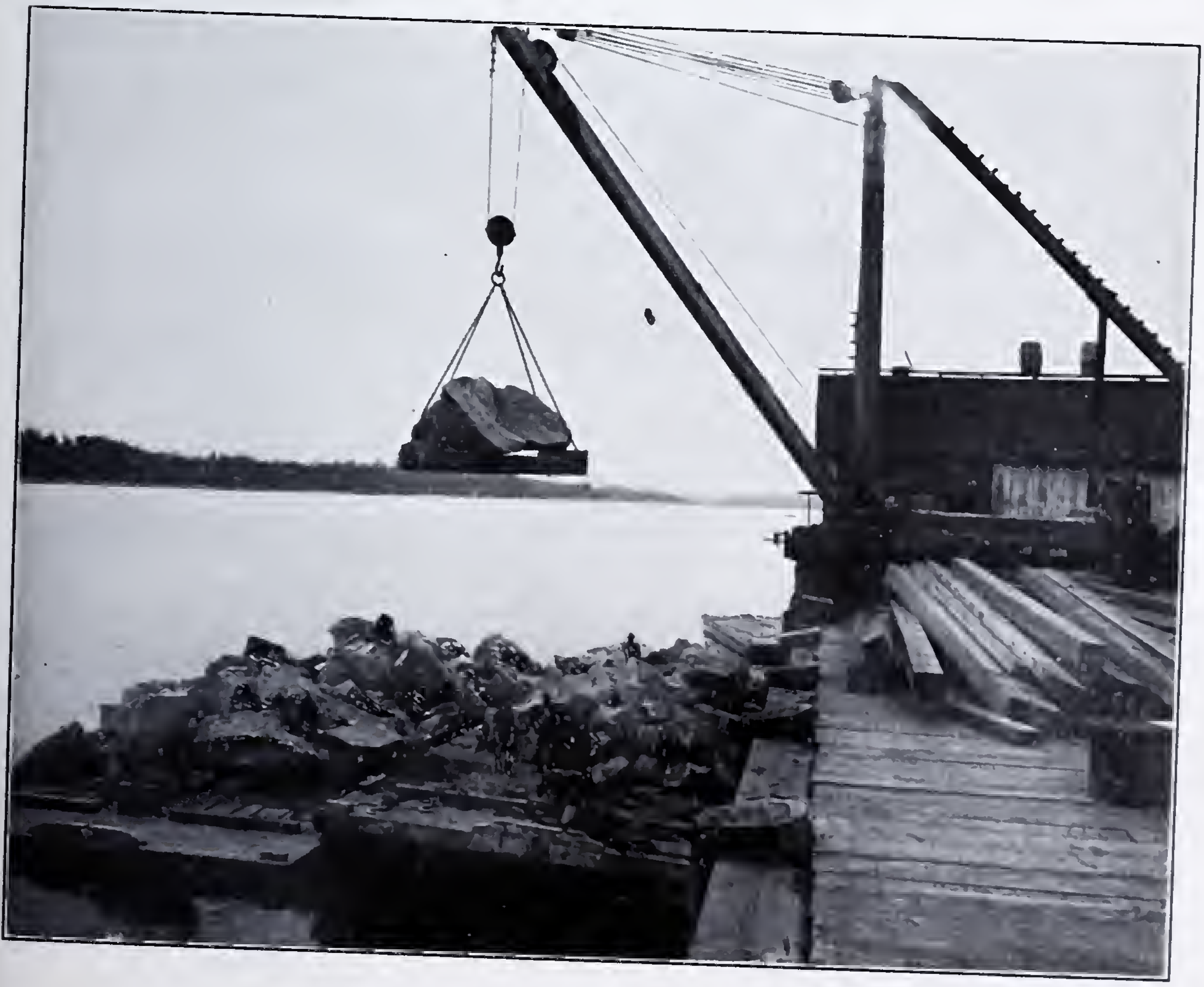


FIG. 2.—UNLOADING STONE FROM SCOWS, COOS BAY JETTY.

nd wave action at their ends being sufficient to keep the entrances lear.

It is undeniable that the construction of jetties at the mouth of a ay produces a violent change in the natural condition of the entrance, nd that it requires some time for the natural forces to find a new quilibrium; but at Yaquina Bay, the oldest improvement on this oast, the advancement of the shore line has stopped, and, for more ian seven years, depths considerably in excess of those stated for the roject have been maintained. There is no evidence that any exten- on of the jetties at this place will be needed to continue this favor- ble condition indefinitely. It is believed that at other similarly nproved harbors, as soon as the proper length of jetties is secured, similar stable condition will eventually obtain.

Other engineers have feared that two jetties interfered with the sy influx of the flood tide, and might damage the interior of the bay lowering the high-tide level and lessening the scour. This result as not been found in practice on this coast. On account of the nproved channel through the bar, caused by the jetties, or for her reasons not understood fully, the mean tidal range has been oticeably increased at Coos Bay and at the Coquille River, while at aquina Bay no reduction in tidal range is noticeable. It is of urse conceivable that in laying out the plan for jetties the distance art at their outer ends might be made too small, but with double ties properly designed it appears that no further effect is pro- ced than would be caused by moving the throat or the gorge to a w point.

Description of Coos Bay.—Coos Bay lies on the Pacific Coast of Ore- n, about 200 miles south of the mouth of the Columbia River, and out 440 miles north of San Francisco. It is the most important rbor between San Francisco and the Columbia River, excepting, rhaps, Humbolt Bay, in Northern California, the commercial value which is somewhat greater. Coos Bay derives its commercial im- rtance principally from the beds of coal and extensive timber lands nd in close proximity to the bay, which furnish the chief exports. e coal is not of the best quality, being a lignite, but in the great rcity of coal on this coast these measures are valuable. Large ests of Oregon fir, much white cedar and considerable myrtle are nd in the vicinity.

The commerce of the bay during the calendar year 1899 was shown in Table No. 1.

TABLE No. 1.—RECEIPTS AND SHIPMENTS, COOS BAY, ORE., FOR 189

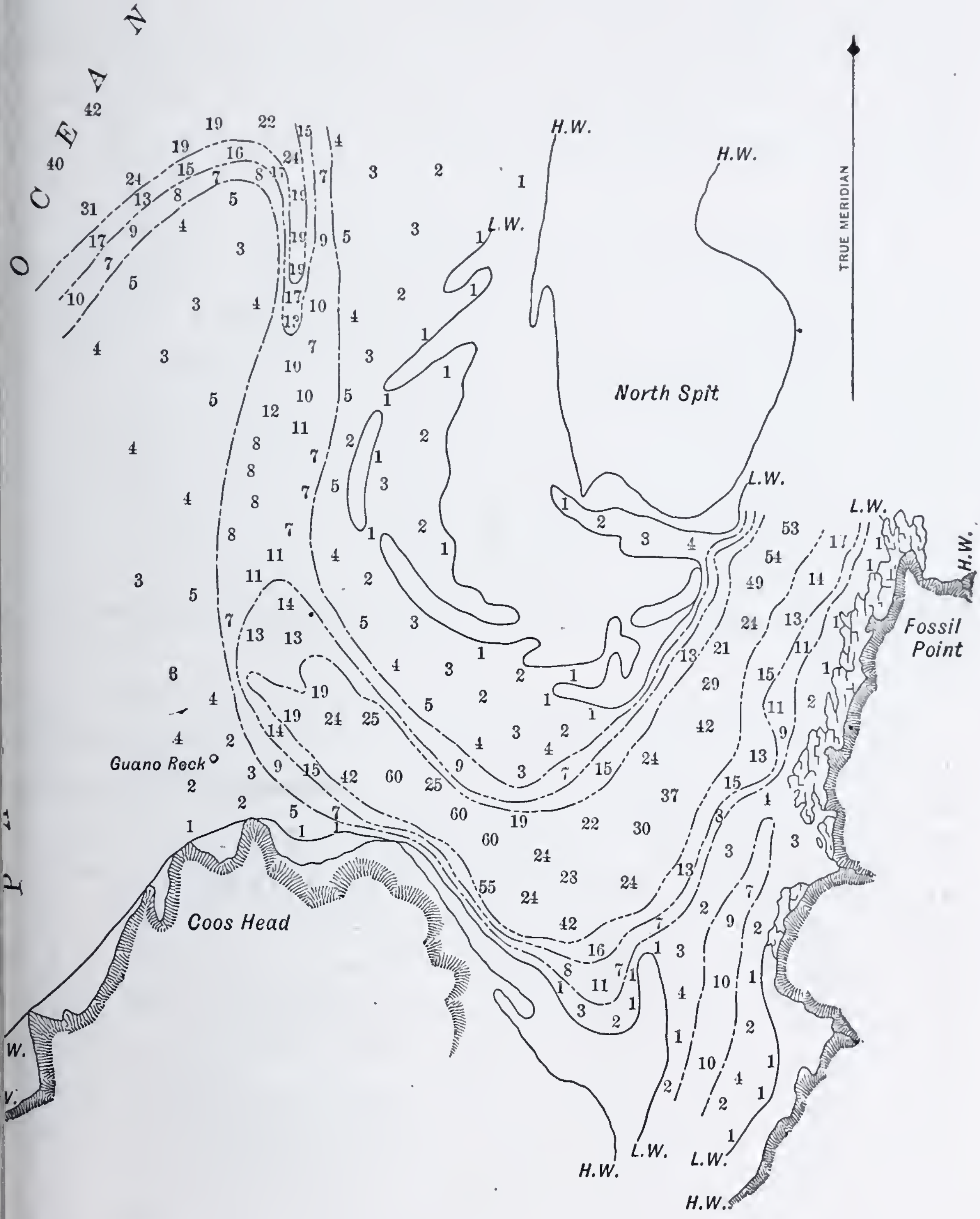
ARTICLES.	TONS.	ARTICLES.	TONS.
RECEIPTS.		Shipments—(*Continued*).	100 396
Miscellaneous freight	10 460	Apples and potatoes	501
SHIPMENTS.		Butter and cheese	554
Coal	56 717	Hides and leather	84
Lumber (27 082 815 ft. B. M.)	40 625	Cattle and hogs	269
Laths	282	Fish	485
Firewood	50	Woolen goods	56
Matchwood	164	Miscellaneous	3 762
Piles, poles and spars	2 553	Total shipments	106 107
Cranberries	5		
	100 396		

The value of this commerce is estimated at $2 558 000.

The only connection between the area tributary to Coos Bay a the outside world is by water, there being nothing thus far but wag roads (almost impassable in winter) over the Coast Mountains connec ing with the rail lines of the Southern Pacific Railroad between Po land, Ore., and San Francisco, Cal. Practically all the commerce this region, therefore, passes over the Coos Bay bar.

Surveys of Coos Bay, made in 1863, 1879, 1885, 1894 and 1899, a shown in Figs. 1 to 5.

The tidal area of the bay is 24 sq. miles. There are no rivers of a special importance emptying into it. The mean range of the tide the bar is 4.8 ft. The average mean discharge on an average ebb ti is estimated to be about 133 000 cu. ft. per second. The discharge neap tide is 96 000 cu. ft. per second, while that on maximum tides about 310 000 cu. ft. per second; ranges of 8 ft. above zero and 2 below zero being occasionally observed in a single day. Surfa velocities of 4½ miles per hour on low ebb tides have be observed. The entrance to the bay from the ocean lies betwe a high, rocky headland on the south called Coos Head, and a lo low sand spit on the north; the width of the opening at the natu throat or gorge being about 1 900 ft. Coos Head is a bold, ti bered headland about 60 to 80 ft. above low water, and is compos of a soft, argillaceous sandstone. It extends to the southward for couple of miles, terminating at Cape Arago, where the Governme



ENTRANCE TO

COOS BAY, OREGON

U.S. Coast and Geodetic Survey of 1863.
Soundings are in feet below mean lower low water.
Mean rise of tide above plane of reference, 5.6 feet.

SCALE
1000 500 0 1000 2000 3000 4000 Ft.

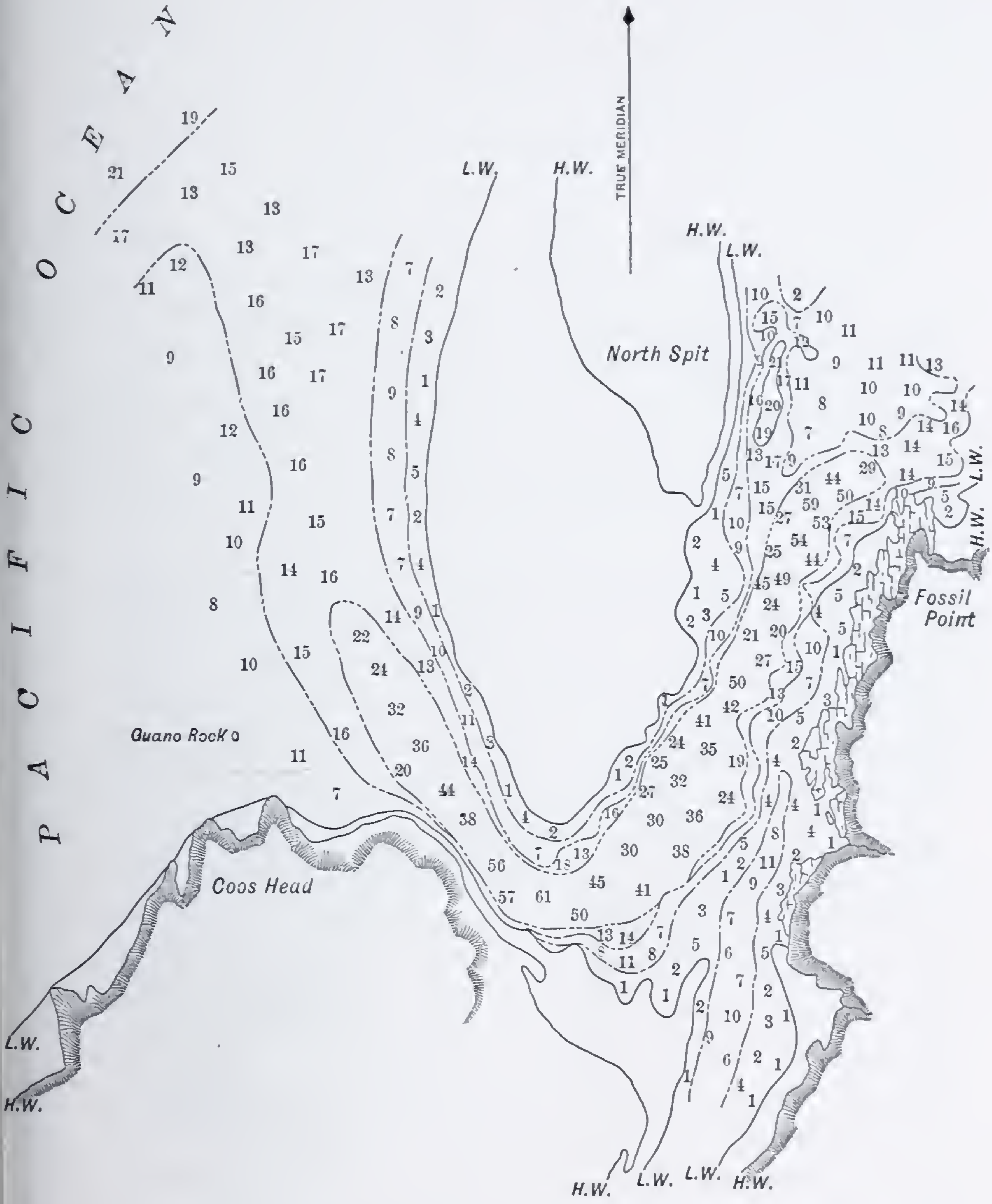
FIG. 1.

maintains a lighthouse. The sand spit to the north of the entranc is about 6 miles long and from ½ mile to 1½ miles wide, with hillock or dunes of from 20 to 30 ft. in height. It separates the bay from th ocean. The sand beach, of which this spit is the southern enc extends unbroken to the Umpqua River, a distance of 20 miles to th north.

In its original condition, the sand bar in the ocean, obstructin the entrance to the bay, carried depths of usually not over 9 ft. a low water, as shown in the surveys of 1863 and 1885. Occasionally better depths would prevail, when new and more direct channe through the bar were scoured out, but they were temporary only The channel was likewise as subject to variation in location as i depth. The encroachment of the sand of the north spit oftentime forced the portion of the channel just inside the entrance down int the opening into South Slough (see survey of 1879, Fig. 2), and th currents thus impinging against Coos Head were turned sharply to th northward.

This tendency of the north spit and that of the south spit to exten themselves across the entrances were two influences which helped t keep the channel in its northern location. This action continued unt the channel, after emerging from the entrance, frequently had a location following close to the west side of the north spit for over a mi before turning to sea. This location usually gave insufficient depth on account of the great waste of the ebb over the long bar, in additio to forcing vessels to pass "broadside on" to the heavy seas for over mile before being able to cross out to sea. The survey of 1879 show this channel crossing what is now the line of the present jetty, nearly mile inside of its present sea end. Occasionally, in severe storms, th north channel would be closed at its outer end, and a new channel woul then break through the bar on a line nearly west from Guano Rock. I this location best depths were always found; occasionally, as much a 30 ft. at high water being reported. This is practically the line of th present improved channel. This new location and depth would las usually but a short time, the channel then working again to the northward in its cyclic change of position.

In addition to the sand carried into the bay by storms an currents, great quantities were blown in during the summer b northwest winds. This sand, coming originally from the ocea



ENTRANCE TO

COOS BAY, OREGON

Survey of Engineer Department, U.S. Army, August, 1879.

Soundings are in feet below mean lower low water.

Mean rise of tide above plane of reference, 5.6 feet.

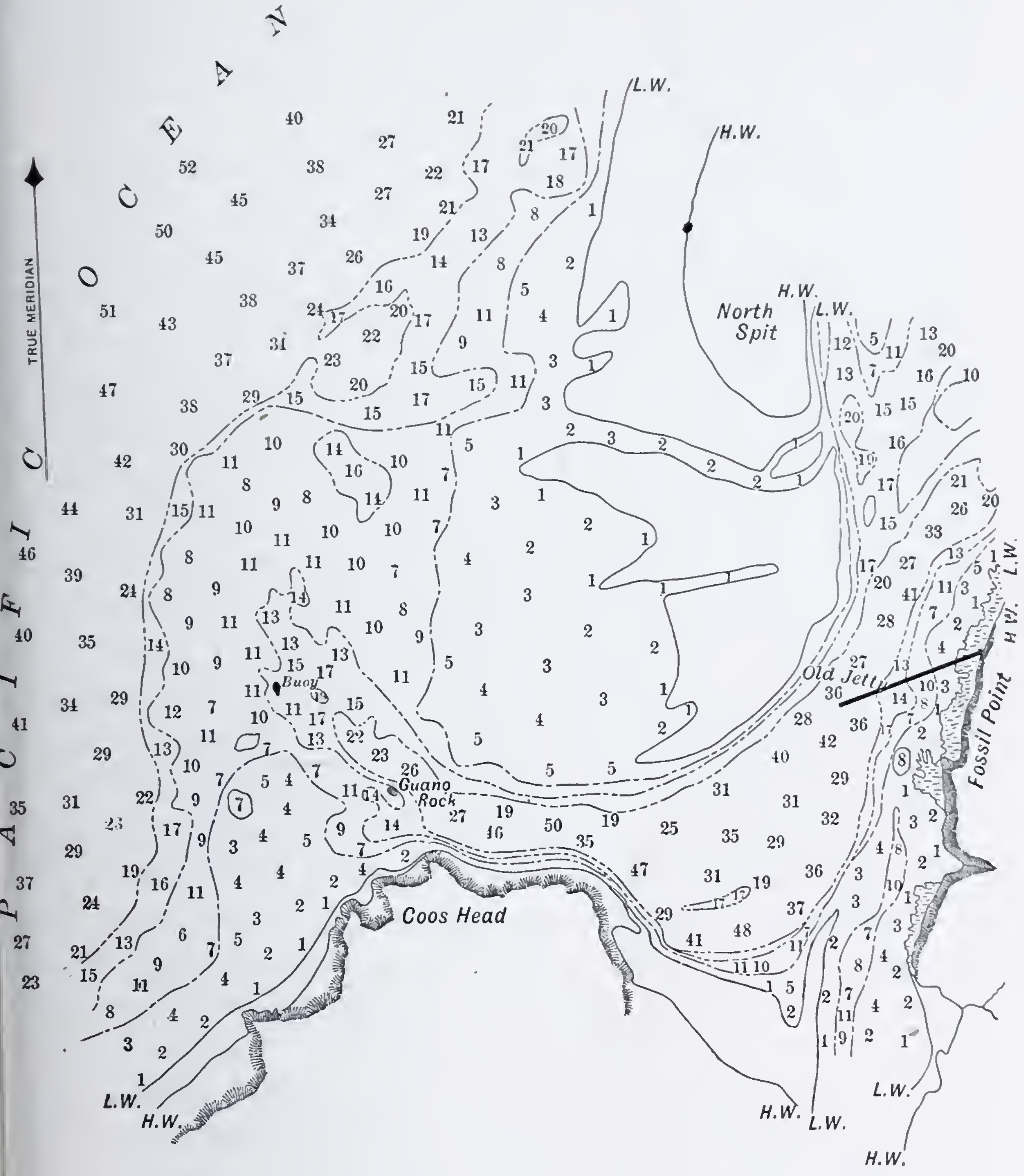
FIG. 2.

bottom, and having been thrown up on the beach in storms, after drying in the air, is easily picked up by the wind, and great quantities are blown into the bay. Some of it is deposited in the bay, and much of it is carried by the tidal currents out to sea where it is deposited on the bar or again thrown on the beach, to again pass through this cycle. The checking of this action was an additional problem.

Plans of Improvement.—The earliest plan of improvement, adopted in 1879, was by the construction of a jetty inside the entrance, where it was protected from storms, and extending nearly westward from Fossil Point (see 1885 map, Fig. 3). This jetty was built of rip-rap rock to a length of over 1 700 ft., and caused a cutting away of the end of the north spit, but had no useful effect on either the direction or depth of the bar channel. This project was abandoned in 1889.

The present plan of improvement of Coos Bay was devised in 1889 by a Board of Officers of the Corps of Engineers, U. S. Army, consisting of Colonel G. H. Mendell, Major W. H. Jones and Major Thomas H. Handbury. This project provided for the construction of two high-tide, rubble-stone jetties, laid as far as practicable on brush mattresses, one extending out from Coos Head, a distance of 4,200 ft., and one from the southernmost end of the north spit, 9 600 ft. long, both converging toward the bar and terminating at a distance apart at their outer ends of 1 500 ft. The function of these jetties was to control the sand movement at the entrance to the bay, to direct the tidal scour upon a special part of the bar, with the expectation of securing a minimum depth of 20 ft. over the bar at mean lower low tide, and afford an entrance along the most navigable lines. The project also included experiments looking to the holding of the sands of the north spit by means of suitable grasses, trees or sand fences, as seemed best, with a view to reclaiming this sand spit and checking the drifting sand. The total cost was estimated at $2 466 412. Between September 19th, 1890, and March 3d, 1899, inclusive, five appropriations, amounting to $675 000, were made. This amount has now completed the north jetty as planned at less than half the estimated cost.

After a careful study of the local conditions, it was considered best to build the north jetty first, leaving the south jetty to be constructed when the needs of the harbor made it necessary. In this way, the large



ENTRANCE TO

COOS BAY, OREGON

Survey of Engineer Department, U.S. Army, July, 1885.

Soundings are in feet below mean lower low water.

Mean rise of tide above plane of reference, 5.6 feet.

SCALE

1000 500 0 1000 2000 3000 4000 5000 Ft.

FIG. 3.

and more important quantity of moving sand could be checked and impounded, as well as the tendency of the channel to turn to the north stopped. It was clearly evident that the north jetty would certainly be necessary, but, before commencing work, it was not so plain that the south jetty could not be dispensed with.

The line of the north jetty follows the general line of the shore end of the north spit, in a curve of large radius, until it reaches a point 1 900 ft. from Coos Head, from which it runs out to sea in a westerly direction along a straight line. The total length of the jetty is 9 600 ft., the outer end being stopped on what was originally the 20-ft. contour before construction commenced, or just short of the bar proper, it being assumed that the energy of the current, conserved and directed by the jetty, would be effective at a considerable distance beyond the jetty's end. On quiet days at low ebb, the current, running straight to sea, is now plainly traceable for a long distance beyond the end of the jetty. A general view of the jetty is shown in Fig. 1, Plate XII.*

Construction.—The jetty construction consisted in dropping along the line of the jetty large rocks loaded on cars from scows and drawn out by a locomotive along the track on the overhead tramway. The tramway was built on pile bents, each consisting of four heavy piles driven 20 ft. or more into the sand bottom, and capped with a 12 x 12-in. x 22-ft. fir stick and sway-braced by 3 x 9-in. pieces of fir. Along these caps were placed four stringers, 12 x 16 ins. x 32 ft., breaking joints, and on these were laid 30-lb. steel rails for the tracks Originally, no ties were used, but later, when a greater speed for the trains was desirable, 3 x 6-in. ties were put in. These two tracks were each of 3-ft. gauge, and were spaced 13 ft. apart, center to center The track started with an elevation of 22 ft. above low water at the receiving wharf, but rose on a slight up-grade until a height of 28 ft above low water was reached at the outer end. This was the leas height at which work could be carried on without much interruption from the waves.

All piles were sunk into place by means of a hydraulic jet operating from a revolving pile-driver† running on the four rails, and havin enough overhang to drive a new bent 16 ft. in advance of the end o

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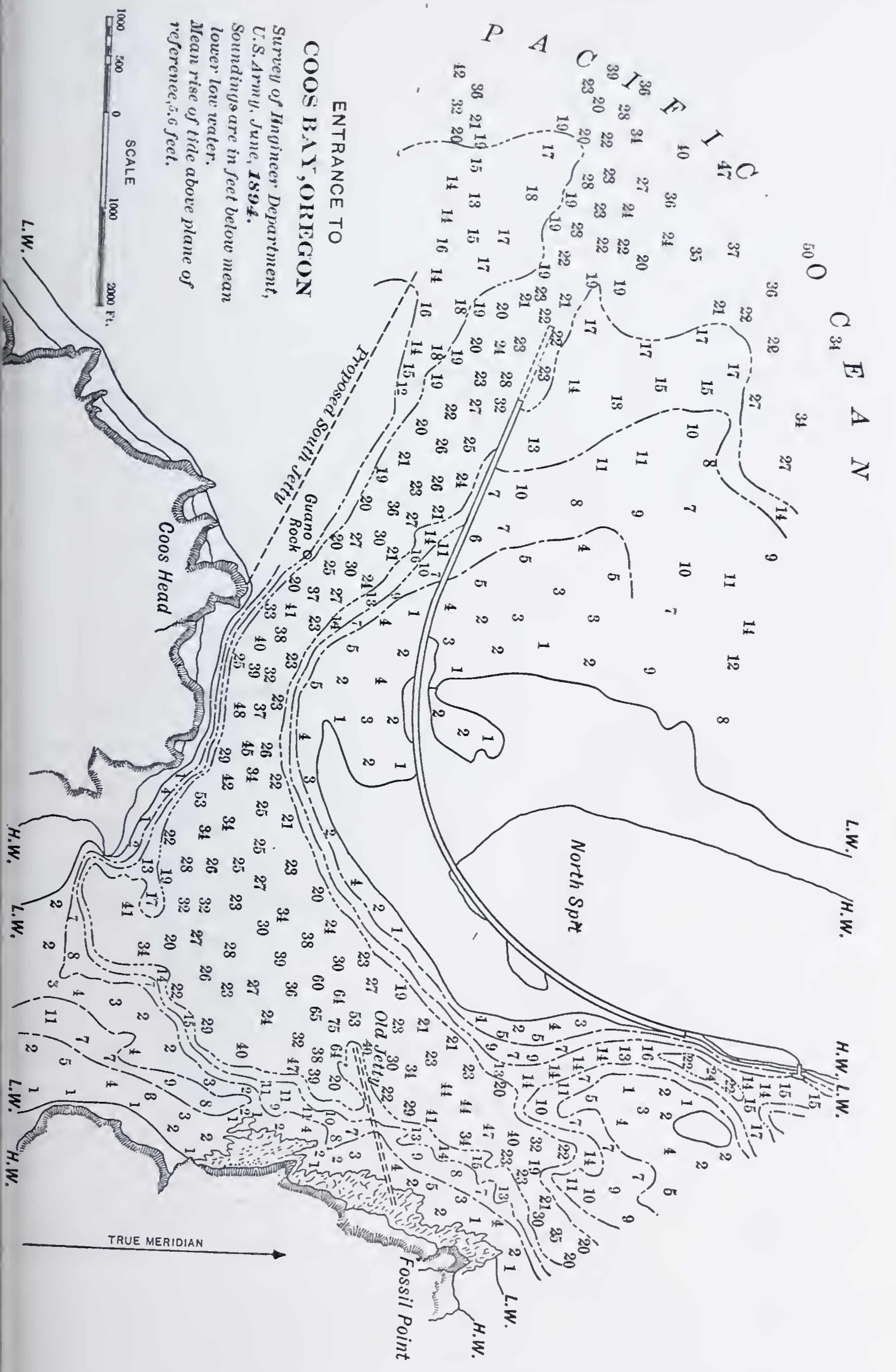
* See, also, paper by T. W. Symons, M. Am. Soc. C. E., entitled "Jetty Harbors o the Pacific Coast," *Transactions*, Am. Soc. C. E., Vol. xxviii, Plate xxiv.

† A view of this pile-driver may be found in Mr. Symons' paper, "Jetty Harbor of the Pacific Coast," in *Transactions*, Am. Soc. C. E., Vol. xxviii, Plate xxii.


ENTRANCE TO
COOS BAY, OREGON
Survey of Engineer Department,
U.S. Army, June, 1894.
Soundings are in feet below mean
lower low water.
Mean rise of tide above plane of
reference, 5.6 feet.
SCALE
1000
500
0
1000
2000 Ft.
PACIFIC OCEAN
Proposed South Jetty
Guano Rock
Coos Head
North Spit
Old Jetty
Fossil Point
L.W.
H.W.
TRUE MERIDIAN

the rails. The piles were 18 to 20 ins. in diameter at the butt, an varied in length from 45 ft. at the shore end of the jetty to 80 ft. a the outer end of the tramway. They were sunk to grade, so that no cut off was necessary, thus considerably expediting the work. As many a five bents were placed in a single day, under favorable conditions, an 1 260 ft. of tramway, complete, were constructed in one month.

This tramway construction caused a scour around the piles as fas as built, so it was followed as soon as practicable with brush mattresses to hold the bottom until the rock could be dumped. Thes mattresses consisted of brush fascines, or round bundles, 20 ft. lon and about 1 ft. in diameter. They were bound together into mattresse between layers or grillages of poles after being brought to the neede thickness by laying several layers of fascines at right angles. At eac pole crossing, the upper and lower pole grillages were bound tightl together with stout rope lashings passing through the body of th fascines, in this way compacting the mattress. The mattresses to b placed between the outside rows of piles were made below the track the lower layer of poles upon which the mattress was built being su pended for this purpose from the tramway by ropes. Upon completio the mattress was lowered to place, weighted with small rock and sun The side mats were made on shore, brought out on a car, dumped ove board, pulled into place by lines, weighted with small rock and sun in place. The side mattresses were usually about 20 ft. square, and t center ones were from 48 to 80 ft. long by 20 ft. wide. They were usuall made from 3 to 5 ft. thick. The main enrockment then followed.

The rock was in pieces weighing on an average about 2 tons*, an was a sandstone of only moderate hardness, weighing about 145 lbs. p cubic foot. It was quarried on Coos River, about 23 miles from the jett

Seven scows, costing about $2 000 each, and each carrying abo 290 tons, were built for this work by the Government. These we loaded and towed to the jetty, so that two scows each day could unloaded. For several months, deliveries of 16 000 tons per month the jetty were made, under favorable conditions. Up to 1896 t Government contracted for supplying the rock on scows at the recei ing wharf on the north spit and unloaded it by hired labor, but, aft this date, contracts were made for the stone in place on the jetty.

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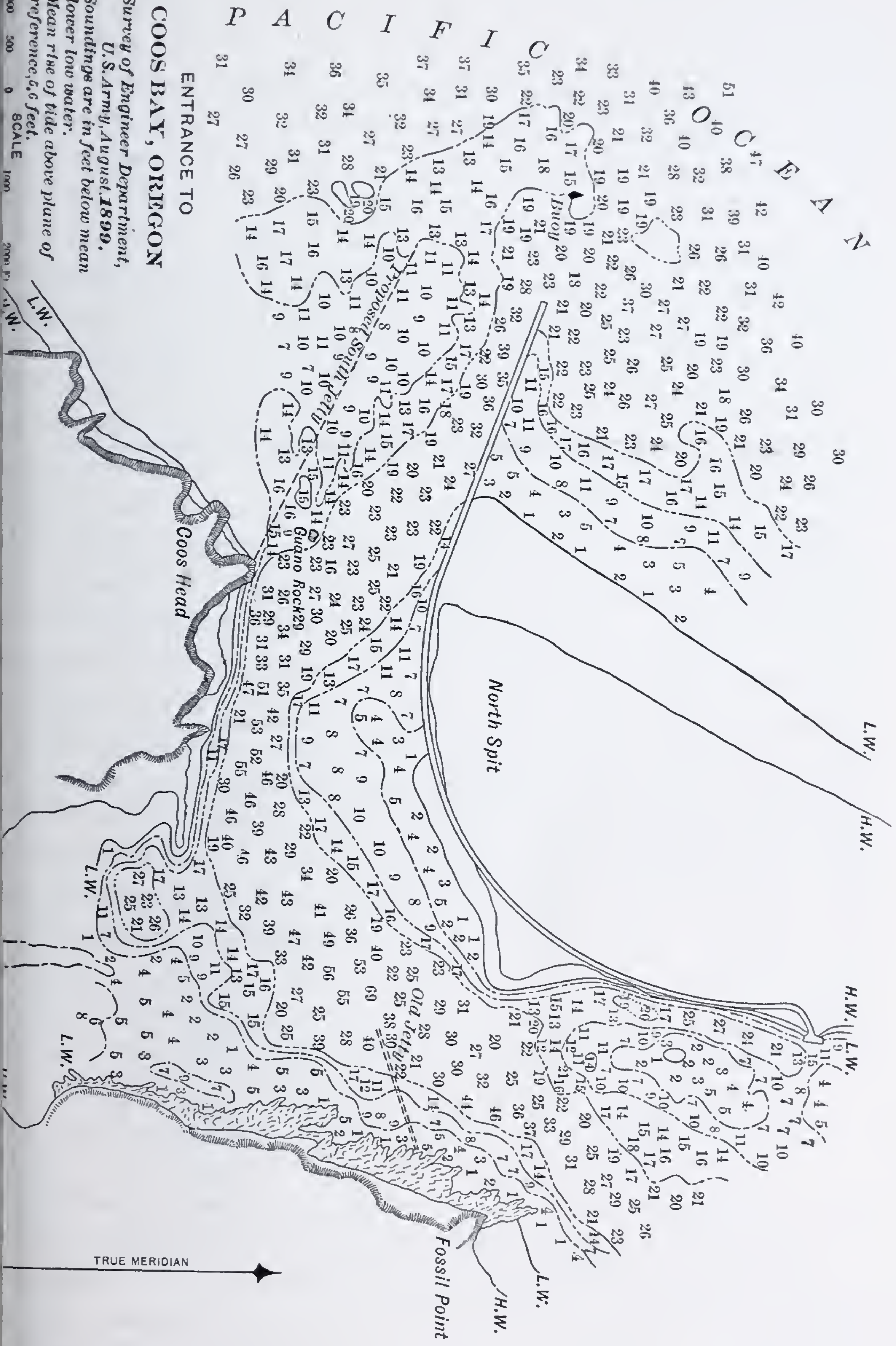
* A view of the dump cars, loaded with rock, may be found in Mr. Symons' pap "Jetty Harbors of the Pacific Coast," in *Transactions*, Am. Soc. C. E., Vol. xxv Plate xxiii.



ENTRANCE TO
COOS BAY, OREGON
Survey of Engineer Department,
U.S. Army, August. 1899.
Soundings are in feet below mean lower low water.
Mean rise of tide above plane of reference, 6.6 feet.

Dumping from both tracks continued until the mound was well above high-water line, an extra amount, to provide for beating down by waves, being placed at the outer end when that part was built. The slopes were those which the enröckment took naturally under wave action. Sections recently made at the outer end, where the worst wave action takes place, show that below a level of 15 ft. below mean lower low water the slope is about 1 on 1, but above this level the slopes were about 1 on 3. Two 15-ton derricks were used on the wharf in unloading, the stone being measured at first by water displacement of scows, but later by track scales. The latter method is by far the more satisfactory, both to the contractors and the Government.

The dump cars* were of a special pattern, designed by Mr. A. Seymour Fleet. They were arranged so that the car platform was removable, making a skip that could be loaded on the scow and then hoisted to place on the car. The skip when in place on the car was swung on horizontal trunnions so that when loaded the equilibrium was unstable, the skip and the load being held in position by a rack and pinion worked by a worm gear at one end of the car. This worm gear was arranged so that the stone when once started could be dumped on either side by turning the worm; the gear could be thrown out of action by removing a pin, allowing the stone to go by the run. The center of gravity of the empty car platform was so placed that its weight tended to return it to place. This design made it possible for one man to dump a train of six or seven cars in a few minutes. Cars of this pattern were used extensively on the Columbia River jetty, where they were likewise found very satisfactory.

Cost.—The entire plant used on this work, with its original cost, consisted of the following:

20 geared dump cars, at about..........	$800 each.	$16 000
2 Baldwin narrow-gauge locomotives, at	3 500 "	7 000
1 Fairbanks track scales................		400
2 15-ton Lidgerwood hoisting engines and derricks, at..................	2 000 "	4 000
7 300-ton deck scows, at..............	2 000 "	14 000
1 towboat		10 000
1 revolving track pile-driver, entire....		12 000
Wharves, buildings and small tools, about..........,....................		11 600
Total.....................		$75 000

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* A view of the dump cars, loaded with rock, may be found in Mr. Symons' paper "Jetty Harbors of the Pacific Coast," in *Transactions*, Am. Soc. C. E., Vol. xxviii Plate xxiii.

The detailed cost of the work was approximately as follows:

Brush fascines	$1.75 to $2.25 per cord.
Poles	17½ cents each.
Piles delivered in rafts at the work	3¾ to 5½ cents per linear foot.
Rails, 30 lbs. per linear yard	$48 per ton delivered.

Common labor, $1.75 to $2.00 per day, and other labor in proportion.

The jetty tramway, complete, but exclusive of superintendence or plant, cost $3.25 to $4.60 per linear foot, depending on the length of the piles used. The average cost was $3.60 per linear foot.

The average cost of the mattresses in place was 78 cents per cubic yard.

The average cost of the stone was 60 cents per ton, made up as follows:

Quarrying and loading on scows	38	cents	per ton.
Towing to jetty	9	"	"
Unloading and dumping in place	13	"	"
Total	60	"	"

The total cost of the jetty was about $70.30 per linear foot, the average quantity of stone per linear foot being 67 tons. The outer 1 000 ft. have taken much more than the average, 350 tons per linear foot for this distance being placed. This has been mainly to make up for subsidence caused by storms.

The average cost per linear foot shows very favorably when compared with others on this coast:

Yaquina Bay, cost	$106.20	per	linear foot.
Coquille River, cost	70.63	"	"
Columbia River, "	87.00	"	"
Humbolt Bay, "	141.50	"	"

It may be stated, however, that conditions for quarrying and transporting stone at Coos Bay are very favorable for this kind of work.

Results.—In extending the jetty, but little effect on the bar was noticed until the old swash channel to the north of the entrance was closed in 1892. From this time on, as the jetty was extended, the effect on the bar was more favorable with each extension. In 1893, the depth desired, viz., 20 ft., at mean lower low water, was found on the bar, and from that date to the present time this has been the ruling depth. With one exception, in November, 1899, when the depth shoaled for several weeks to 9 ft., due to a long and severe southwesterly storm, a depth of from 18 to 22 ft. has been maintained for seven years. Thus far, this improvement has been eminently successful. Whether the good results already obtained will be permanent without further work in extending the north jetty, or whether the south jetty will be ultimately necessary, cannot be definitely foretold at present. It appears probable, however, from the most recent surveys, that the south jetty will be needed before the occasional lapping of the south spit around the entrance in southwest storms can be controlled.

The shore line has followed out, as the construction of the jetty proceeded, backing up the jetty with sand and thus strengthening the shore end of it, so that but little new work has been necessary on this part since the first work was done. This new shore line is from 1 200 to 2 000 ft. in advance of its original position. The large quantity of sand thus impounded is practically all saved from injuring the channels, and the work of the ebb tides in deepening the bar is thus made considerably less.

Experiments in holding this sand from drifting have been made by planting numerous kinds of trees, grasses and Scotch broom, and by using sand fences. The best results were obtained by using the Holland grass (*Arundo Arenaria*), which has been found so effective at the Golden Gate Park in San Francisco. This plant is of slow growth at first, but when it once takes root it grows with great persistency, catching and holding sand until oftentimes mounds 6 to 10 ft. high are made. Long patches, amounting in all to about 20 acres, have been newly set out, in the belief that it will bind the sand in the areas covered.

Remarks.—In reviewing the details of the construction, two points appear which are not yet sufficiently developed in this kind of construction: One is the value of brush mattress, and the other the means of maintaining to full height the outer ends of the jetties in a sea of such severe storms as are found in the Pacific Ocean.

The function of the mattress is to hold the bottom beyond the end of the enrockment during jetty construction and to prevent the scour which would otherwise naturally take place and thereby add to the quantity of rock necessary. This holding action is probably secured by checking the currents and entangling in the twigs and meshes the sand borne by them. Mattresses also prevent the flow of currents, through the interstices in the enrockment, along the sand of the bottom. Such currents might, by long action, undermine the jetty; and, further, where the expected scour occurs in the channel, it is supposed that if any undermining is caused by racing currents too close to the jetty, the mattress, being flexible, will shape itself to the new bottom and stop further cutting. It has never been shown on this coast that these functions are more than partially performed.

It is believed that the mattresses, after being loaded with rock, are squeezed into very much less than their original volume, probably less than half. The comparatively high cost and difficulty of placing mattresses, and the time occupied, make it appear that, as volume in the completed jetty, the rock is considerably cheaper and better, being unaffected by sea worms. The plan of doing without mattresses altogether has been tried at a special place in the north jetty at Coquille River and in the jetty at Siuslaw River. The time is short since this was done, but no difference in settlement has been yet noticed. At Humbolt Bay, Cal., Lieutenant-Colonel W. H. Heuer, Corps of Engineers, abandoned brush mattresses in 1898, using a mattress of small stone as a foundation for the jetty enrockment at that place. This practice followed experiments of several years in both jetty and spur construction where mattresses of small stone were used with very satisfactory results.* Small rock can follow the tramway construction faster than brush mattress, and much scour around the piles is thus avoided in strong currents. The necessity and wisdom of using mattresses, especially in water more than 15 to 20 ft. deep, is questionable.

A weak point, thus far, in all jetty construction on this coast is the difficulty of maintaining the outer ends to a sufficient height. The heavy seas in storms break over the top of the enrockment and slowly batter down its height. The Columbia River jetty now requires considerable raising at its outer end to compensate for this action. The Humbolt Bay jetties are likewise beaten down at their outer ends. Coos Bay jetty has been twice built to 28 ft. above low water, and twice has been beaten down to below low water, and at the extreme end it was found that previous work, originally built well above high water, had been beaten down to about 15 ft. below low water, this being apparently the limit below which the wave action is not especially destructive. The Coquille River jetties have been somewhat lowered at their outer ends; and at Yaquina Bay, where the jetties are more or less protected by an outlying reef, the subsidence has been unimportant, but even here there has been settlement at the outer ends from high to low-tide levels.

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* Annual Report, Chief of Engineers, U. S. Army, 1898, p. 2949.

It seems plain, after watching the action of the waves at Coos Bay, that this beating down is progressive, commencing at the extreme end only. The jetty is never much damaged back of the outer end. The jetty being almost head on to the usual direction of the severest waves, the largest blocks, weighing 10 to 12 tons, are often picked up first with the advancing wave and then rolled or carried down the slope, with the fall of the water following. Experiments with concrete blocks weighing about 25 tons each were made during last year. These blocks were made in place at an exposed point to see what the action of the sea would be. Several were moved, and one was rolled by the waves down the enrockment to the low-water line. It appears, therefore, that blocks of this size would probably be too small for a permanent random covering for the enrockment. If some solid structure, strong enough to protect the outer end, could be built, it is thought the jetties might be maintained to effective dimensions much more easily. Such permanent end, of course, should not be placed until the proper length of the jetty had been ascertained.

Several methods are suggested by which these outer ends could be better held: One, by using for the enrockment a random covering of large concrete blocks, each weighing about 30 tons or more, for protecting the outer end of the jetty; and another, by constructing a monolith of concrete in bags resting on a broad rip-rap foundation brought up to the level of about 15 ft. below low water, the monolith topped above low water with concrete placed in moulds, the whole placed from a platform resting on iron screw-piles, which could be left to support and strengthen the structure afterward.

DISCUSSION.

Mr. Haupt.

LEWIS M. HAUPT, M. Am. Soc. C. E. (by letter).—This timely paper, following closely on an official report on the improvement of the Brunswick Bar, Ga., calls attention, in a general way, to the methods now pursued and the results attained in the Government practice, and also serves to illustrate the very divergent conclusions reached from similar data.

As the United States is assuming a position of ever increasing importance as a maritime nation, it is of primary importance that the bars obstructing her harbors be removed in such manner as to secure the best depths available at the least annual cost for maintenance.

These harbor problems, therefore, are of national importance, and their discussion, without prejudice, should result in the greatest possible economies and in the substitution of scientific methods for tentative experiments.

This paper is carefully prepared, gives evidence of much research and a clear comprehension of some of the difficulties, and, although mainly directed to the work at Coos Bay, it refers incidentally to several other localities, with conclusions which are so different from those reached by others who have studied the record that the writer takes the opportunity of adding a few extracts for the clearer presentation of all the physical conditions and results.

Taking up the various points in the paper *seriatim*, it is observed that the opening paragraph states that the completion of the north jetty has produced satisfactory results. The author then describes the exceptional violence of the storms of the North Pacific and the exposed condition of the harbor entrances, citing, but not applying, Stevenson's oft-quoted formula, $h = 1.5 \sqrt{d}$, where h is the height of the wave in feet, and d, the fetch in miles.

The danger of using a formula for such computations, in which the constant is fixed and empirical, will become apparent at once when it is considered that for d any distance may be used from 100 to 6 400 miles, and hence h will vary accordingly, so that the wave height may vary (using these values) from 15 to 120 ft. As the maximum waves seldom exceed 40 ft. in height it is evident that the formula has only a limited application, and must be used with caution.

The author next cites the early tentative works constructed within the coast line, which he remarks were only partially successful, but he gives no specific locations. The harbor under discussion, however, shows one instance of a wing-dike built out into the channel from Fossil Point (see Fig. 3) for a distance of 1 700 ft., but which he says, on page 496, had no useful effect on either the direction or depth of the bar channel, and was abandoned in 1889.

Mr. Haupt. There were interior jetties built on the New Jersey coast also, which likewise ended in failure and were abandoned. The single interior jetty at the mouth of Coquille River, Ore., in 1886, showed a low-water depth of 6.5 ft., now 6 ft.

It is almost an axiom in engineering that we learn more from our failures than from our successes; hence, it is of greater service to consider the former seriously and with no reflections upon those in charge of the works, since the actual condition of all the forces which may surround an entrance are occult, and, like those producing earthquakes where least expected, cannot be predicted.

The author very properly recognizes the importance of the resultant littoral movements, the cyclic oscillations of channel, the tidal action of flood and ebb in building and scouring bars, the necessity of conserving the full tidal prism, and especially, as he puts it:

> "To prevent the encroachment of the sand on the channel and at the same time prevent the divergence and dissipation of the effect of the ebb tides, by confining and directing these tidal currents at a selected point of the bar."

He adds, if this can be done by suitable works then "improvement may be confidently expected."

In this he is entirely correct, but the difficulty which arises in their application, is in determining the actual position of the resultant and in so placing the works as to aid the land forces as opposed to the sea forces. One would suppose that, to protect a channel from the predominating drift, the barrier should be placed to the "windward," or between it and the channel, and hence it may excite surprise to find that most of the jetties which are built for this purpose have been located on the far or leeward side of the channel desired to be created, with the invariable result of rolling the bar rapidly seaward. In one case it advanced half a mile in about a year, adding greatly and unnecessarily to the cost of the work. But there are other conditions, in addition to these, which do not yet appear to be fully recognized and applied on ocean bars, one of which is to avoid an abrupt angular change of direction of the ebb currents which wastes their energy in boring deep holes, to no useful purpose. As this is to be merely a discussion of the paper, however, and is not designed to be suggestive of improved devices, it remains to show how the foregoing requirements of the author have been construed and applied in practice.

In the official Report on the Brunswick Bar,* where there are no jetties, and which was deepened 5.6 ft. by the use of dynamite, aided by dredging, it is said:

> "This principle requires the jetty to be located upon that side of the channel toward which the latter is being driven by the drifting sands. To use a phraseology analogous to that which has been used in other cases, it should be on the leeward of the channel."

To make this still plainer as to the intention, it is added:

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* Document, 355, H. R., 56th Cong., 2d Sess., Jan., 1901.

Mr. Haupt

> "A single jetty on this principle at Brunswick would be located on the south of the channel, since the drifting sands come from the north."

He then goes on to illustrate, by saying:

> "A single jetty at Coos Bay, Oregon, has been built in accordance with this theory, and appears to have been successful in increasing the depth from 10 ft. to not less than 18 ft., which latter it has maintained for the last 5 years."

Here the north jetty is the only one built, while the paper states that the resultant drift comes from the south. It must, therefore, strike the jetty on its south or channel side, and hence the jetty does not fulfil the condition laid down by the author of this paper, viz., "to prevent the encroachment of the sand on the channel," while it does comply with the incorrect location suggested in the Report on the Brunswick Bar by being placed to the leeward of the channel with reference to the prevailing drift. Both of these theories cannot therefore be correct, and the case requires further examination to ascertain which is right. As the results are pronounced satisfactory by both authors it becomes necessary to look further into the records as to the original conditions, and to ascertain present effects on bar movements.

The depths prior to improvement are shown on the several charts of the paper, and which contain an admirable object lesson for the reader. In 1863 when the channel was flexed farthest north and was inside of the meridian through Guano Rock the ruling low-water depth was 7 ft. As it receded to the south in 1879 it is shown as being 13 ft.; again, in 1885, it is 8 ft., but farther out to sea; in 1894, with the jetty well advanced, it is 19 to 20 ft., with the 18-ft. contour south of but parallel to and beyond the jetty; and four years later, with the jetty completed, the depth is given as 19 ft. on the chart (18 to 22 ft. in the text), and it is 1 000 ft. farther seaward, with the 18-ft. contour overlapping the line of the jetty produced. During November, 1899, "the depth shoaled for several weeks to 9 ft., due to a long and severe southwesterly storm." The author, therefore, adds:

> "It appears probable, however, from the most recent surveys, that the south jetty will be needed before the occasional lapping of the south spit around the entrance in southwest storms can be controlled."

In this respect the writer is pleased to agree with the author, for the reason that such a jetty will fulfil to the best advantage the main requirements of this inlet, but it can be placed much more effectively than on the broken line, as suggested on Figs. 4 and 5. This plan reduces the improvement to two high-tide jetties which have more serious objections than the author appears to attach to them, and which are worthy of consideration. The jetty now in place has apparently prevented the channel from drifting to the north where the energy was wasted and the sea more dangerous, being broadside; but the author has stated that at times, when the cycle was complete, the

Mr. Haupt. north channel closed and a new one opened abreast of the gorge of the harbor, when depths of 30 ft. at high water were reported. Deducting the tide of 5.6 ft. would give 24.4 ft. as the natural mean low-water depth over the bar, when the channel is in this position. So that the natural depths were, say, about 5 ft. better before improvement than those now existing. But the report of the Assistant Engineer in 1892, which appears to have been overlooked in all references to this work, states that the depth here prior to the beginning of the work was, at times, 27 ft. at mean low water, so that it would appear that for this position of the channel the unimproved depths should range from 24½ to 27 ft. instead of from 18 to 22 ft., or that there has been a loss of from 6½ to 5 ft., due to the effort to fix the location of the channel by a jetty placed to "leeward." Had it been placed to windward there is no doubt, in the writer's opinion, that the depths would have been greater and the bar advance less, with the further great advantage of acting as a breakwater for navigation, placing the vessel to leeward of the jetty instead of to windward in the great storms from the southwest.

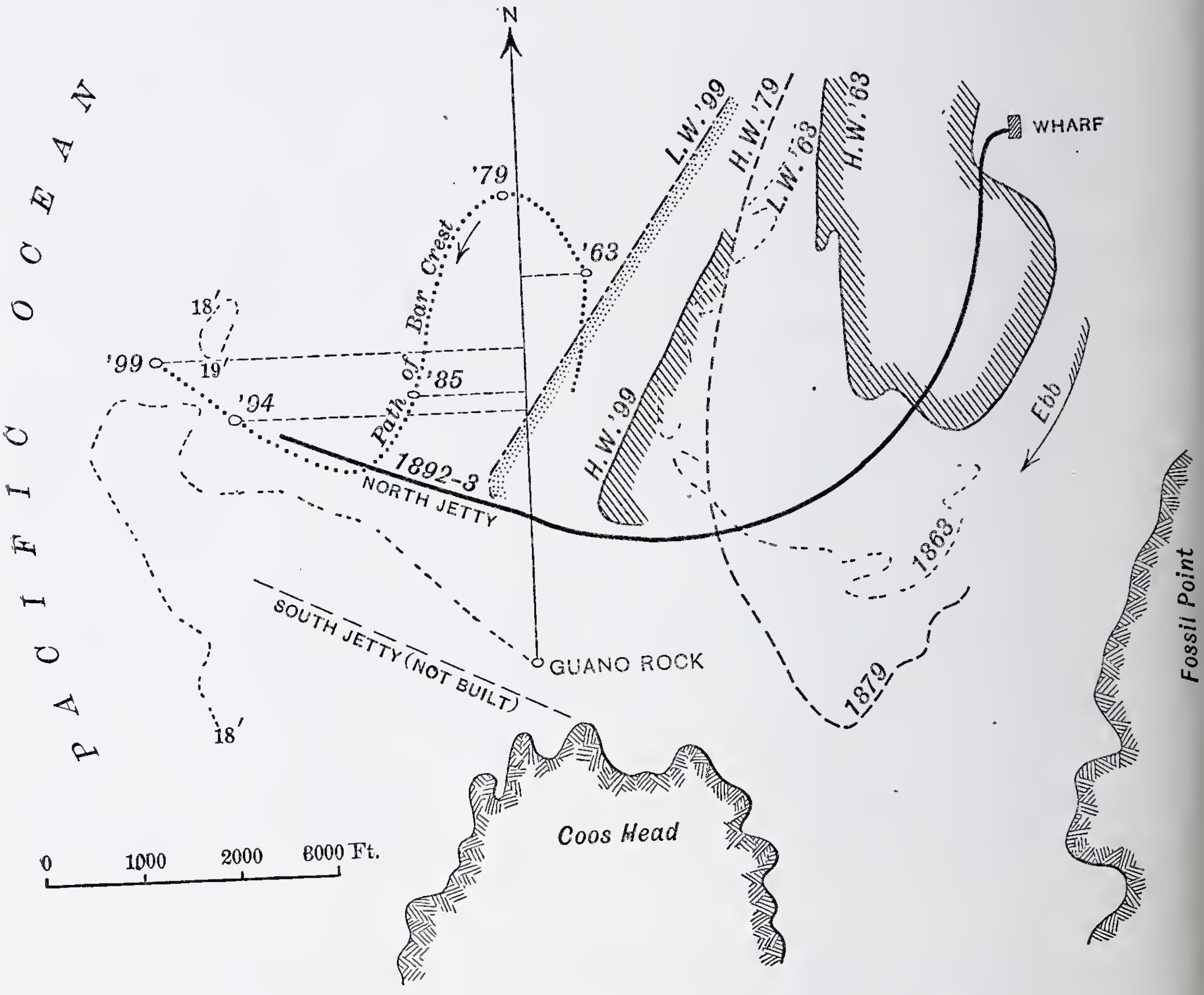

FIG. 6.

The movements of the bar are perhaps more clearly illustrated by plotting the location of the crest at the date of the several surveys and connecting them by a line showing the locus of this movement. As the actual crest is an area and not a point, this method is merely a guide, but it is relatively correct. The seaward movement is given here in departures from the meridian through Guano Rock as a well-defined fixed point, and hence they are not quite normal to the coast. Mr. Haupt.

The author states that the jetty "stopped on what was originally the 20-ft. contour * * * or just short of the bar proper," leaving it to be seen from the chart that the bar has advanced, which is a thing to be avoided. He does not appear to pay any particular attention to this feature, and hence the diagram, Fig. 6, will serve to show the rate and direction of this movement which is of great importance.

Table No. 2 gives the rate of movement for the intervals between surveys.

From Table No. 2 it appears that the bar crest has been advancing most rapidly seaward since the construction of the jetty, with every tendency to overlap it and ultimately repeat its cyclical peregrinations in a more exposed position. Under these conditions, can the work be classed as a success in its present transition state?

TABLE No. 2.

Survey of—	Period, years.	Total departure, in feet.	Average advance per annum, in feet.
1863–79	16	1 100	70
1879–85	6	1 200	200
1885–94	9	1 500	166*
1894–99	5	1 000	200
General Averages of Advances.			
1863–99	36	4 800	133
1879–99	20	3 700	185
1885–99	14	2 500	150
1894–99	5	1 000	200

* Jetty partly built.

Two Jetties.—As to the effects upon the harbor from the use of two jetties, the author believes that:

"With double jetties properly designed it appears that no further effect is produced than would be caused by moving the throat or the gorge to a new point."

This conclusion does not seem to accord with observation, as it is recorded that double jetties have reduced the tidal inflow very seriously and caused a silting up of the harbors. To shift the throat so much further seaward is, in itself, an injury, as the resistance to discharge is increased by the longer channel; the entrance is partially

Mr. Haupt. dammed up and the area of the gorge on the bar site is also contracted. The present gorge shows depths at the point of incidence of ebb currents on Coos Head of 60 ft. in 1863; 61 ft. in 1879; 50 ft. in 1885; and, after the jetty was started in 1892, of 48 ft. in 1894; and 55 ft. in 1899. These are all reaction, not velocity, depths; an important distinction. An ebb current moving axially between nearly parallel jetties will cause no reaction, and no such depths at the outer throat can result as at the gorge, so that the outer cross-section will be smaller.

Engineers seem to have failed to note the fact that the deep holes at points of incidence or around bends of streams are not velocity depths, but are due to reaction from impact. For instance, in a report on a project for New York Harbor entrance, in 1885, it was proposed to transfer the throat at the Narrows to the outer bar by two rip-rap jetties rising only to low water, or below, and extending from Coney Island and Sandy Hook seaward, closing up the entrance almost entirely. The cost was estimated at $5 000 000 to $6 000 000. The precedent for this project was derived from the existing depths at the Narrows, for the report says:

"The flow through the Narrows * * * maintains a channel a mile wide and with depths of 100 ft. This depth only diminishes to 30 ft. at a point 4 miles below. The mean ordinary velocity at the Narrows is, during the ebb tide, about 2 ft. per second, and from this a depth of 100 ft. results."

The mistake made here is in attributing the depth to velocity, whereas it is due to the reaction caused by the "compression" (or, as some writers prefer to call it, concentration) of the flood tide in entering the Upper Bay. Many instances might be cited of mean velocities of 2 ft. per second flowing over sandy bottoms which do not erode to depths exceeding 4 to 6 ft. Hence it cannot be velocity alone that produces depths of 100 ft., but a much more potent force, viz., impact creating reaction from the bottom.

The effort, therefore, to utilize the gorge depths by reproducing them at the bar end of a pair of jetties has invariably resulted in failure, and still it is recommended to be tried over and over again. The New York project was soon abandoned. The latest instance is found in the Report on the Brunswick Bar, already cited, in which it is said:

"Apparently, if all the ebb tide is concentrated between the jetties on the bar, and their width apart is equal to that of the gorge, the conditions of the latter would be reproduced on the bar. This would require jetties to high water."

The author then goes on to explain that as such depths would be excessive and the cost greater, only low-water jetties are usually built, and adds:

"With this system of construction, however, it has been found that the scouring effect has generally not only failed to reproduce the

Mr. Haupt. depths at the gorge but has not produced depths enough for navigation, * * * (still) the channel location has been fixed so that very satisfactory dredged channels can be maintained," and the experience at Charleston is given as "a good example."

It would seem, that if high jetties would produce "depths far beyond the requirements of navigation," and if low-water jetties having "the width between jetties on the bar generally greater than at the gorge" would "not produce depths great enough for navigation," that between these limits there should be found a happy medium, at which the depths, resulting from tidal scour, should suffice without recourse to dredging.

If Charleston is cited as a good example of dredging, supplemented by jetties, or the reverse, let it be observed that the bar is now about 4 000 ft. beyond the end of the completed jetties, and the original channel was abandoned because of its rapid filling up. Moreover, the jetties are not low-water, but submerged, jetties 15 ft. or more at the inner ends and high-tide jetties over the original site of the bar, so that the reference is hardly germane.

Yaquina Bay.—Yaquina Bay has been referred to in recent publications as an illustration of the success of two high-tide jetties, and the present paper seems to confirm this opinion to some extent. The author says the south jetty did not accomplish all that was expected of it, and it was found necessary to close the old north channel "before much improvement on the bar resulted," so that it is an inference.

This problem and its solution cannot be fully understood without the plan, for it was complicated by dangerous submerged reefs lying off shore which served to create a lee for navigation, and any advance of the bar seaward as the result of two jetties was sought to be avoided by a single south jetty at an acute angle to the shore line, to close, in whole or part, the south channel. This project, as designed (see Figs. 7 and 8), is described in the report of the Chief of Engineers for 1881, page 2592, in these words:

> "The existing plan of improvement provides for a jetty on the south 2 500 ft. long, rising 2 ft. above mean low water," to be built of stone and timber cribs. "Suitable appropriations should be made for an improvement which promises such good results."

The ideas intended to be applied here were to prevent the sand encroachments on the channel and the dissipation of the ebb currents, but it is unfortunate that the means were insufficient to produce the result, and the north jetty became a necessity, so that the original idea was radically changed to one of concentration between two jetties with consequent bar advances, which it was desired to avoid. This is now cited in the Report on the Brunswick Bar (p. 37) as one of the three "only examples of such high-tide jetties in the United States." The other two mentioned are at Sabine Pass and Galveston, both of

Mr. Haupt. which were originally designed to be submerged on their flanks, were subsequently raised to low water and finally to high water to control the sand movements and currents. There are, however, various other high-tide jetties in the United States, which teach the same lesson of congestion of tides and bar advance. While the first jetty, as designed, was being built at Yaquina, under great difficulty and exposure, it was barely awash at low-water, and formed a sharp re-entrant with the shore line. The breakers cut it off from the shore by a breach of 375 ft. width at the inner end, in 1883–4, which was repaired the next year.

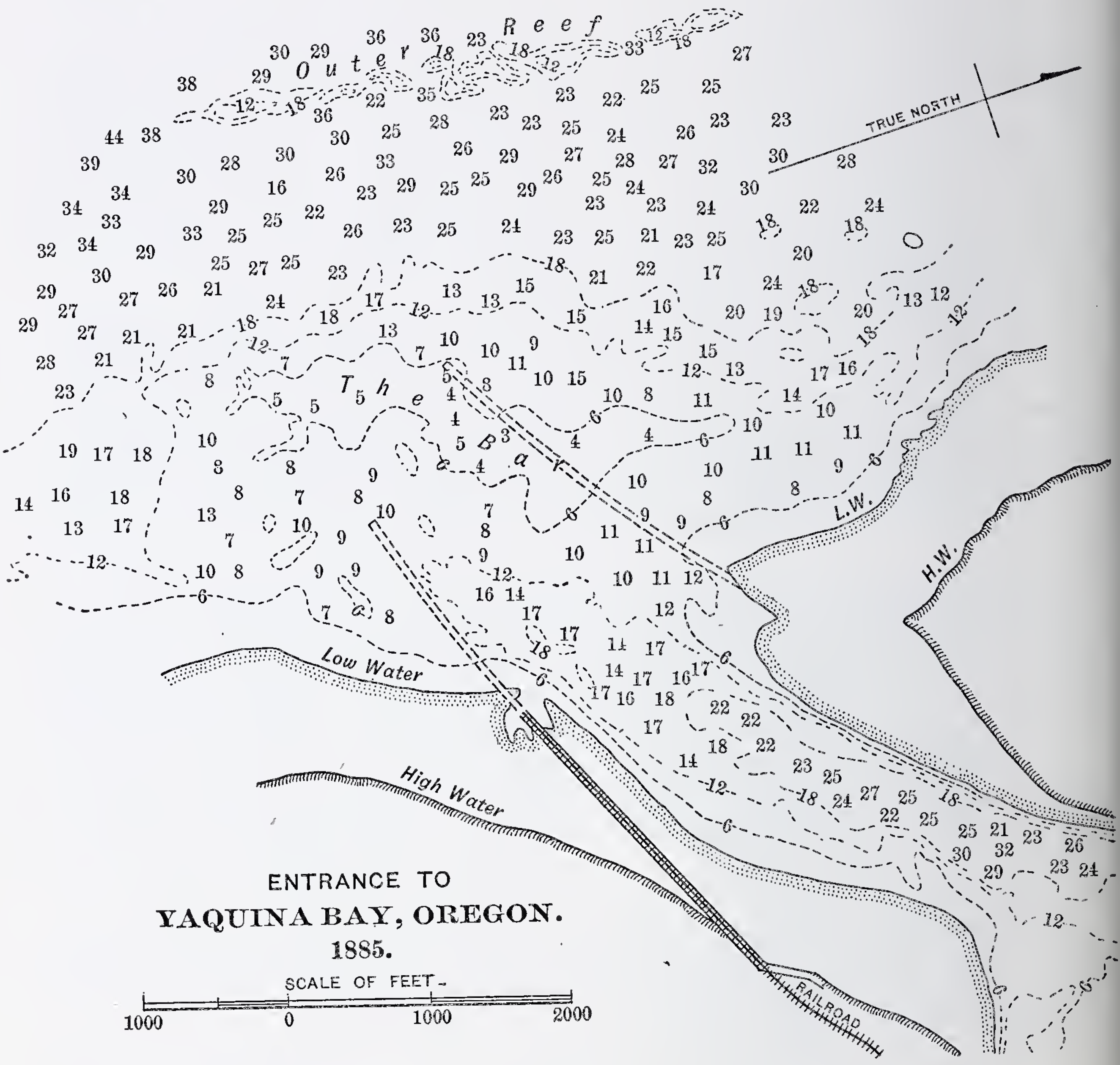

Fig. 7.

In 1886 it was recommended to extend it 1 000 ft., and to build a half-tide north jetty of 1 800 ft., with further extensions of both jetties, the north one 1 200 and the south one 700 ft.; at a cost of $800 000, "in round numbers," if ultimately built to the 18-ft. curve.

The minimum depths reported in the north and south channels were originally 7 to 9 ft. In the central channel at certain seasons there were from 5 to 10 ft. mean low water, while the mean tide is 7.1 ft. The proposed depths are referred to mean high water and were to

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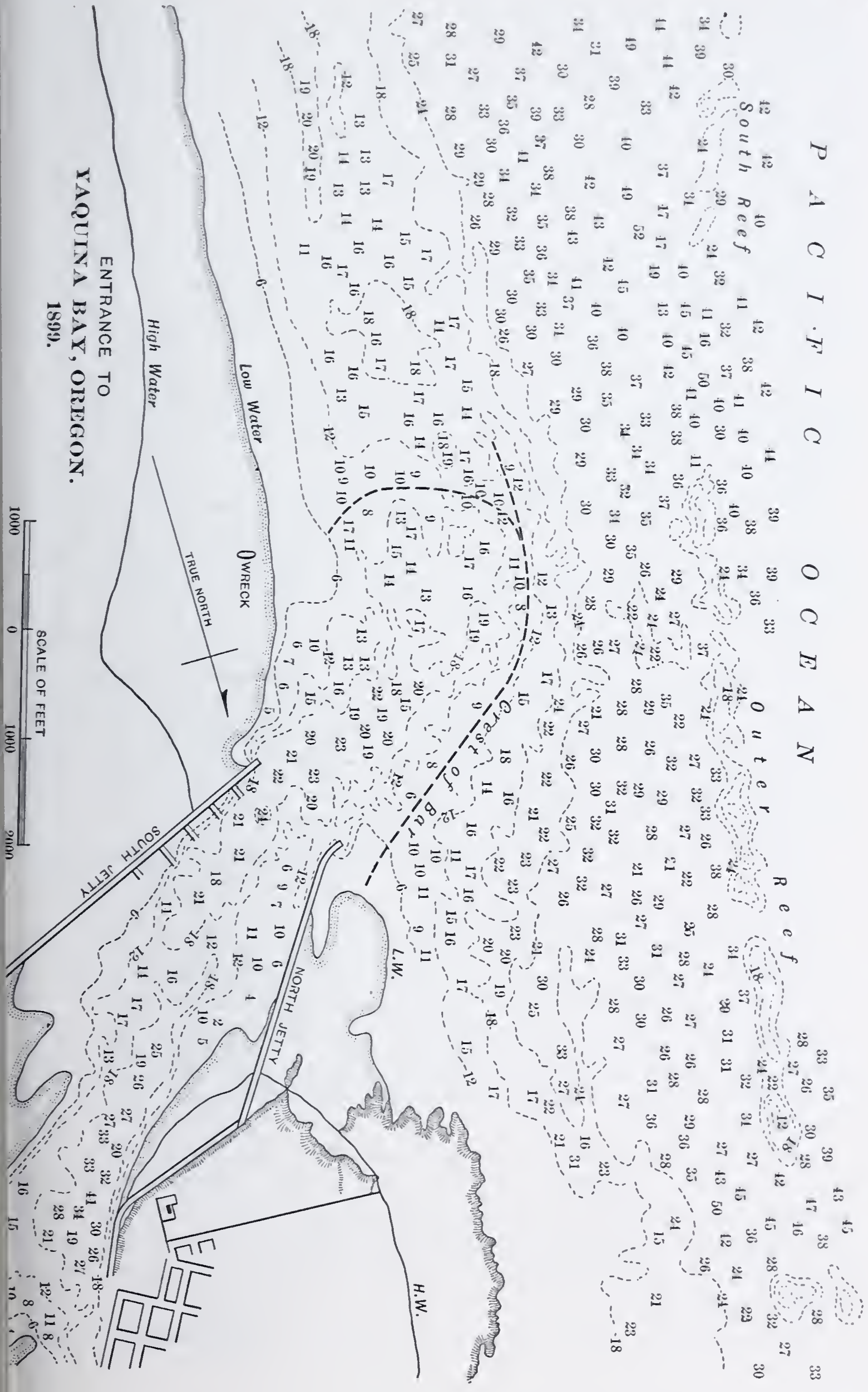

ENTRANCE TO
YAQUINA BAY, OREGON.
1899.

Mr. Haupt. be 17 ft. at first, afterward changed to 19 ft., so that the actual increase above the natural depths existing in the central channel at times would vary, when referred to the same datum, from zero to 2 ft. The report of 1886 contains a map dated 1885 (Fig. 7), which shows that the original 2 500 ft. of south jetty is surrounded by sand, as the low-water line has advanced beyond its end, and the depths in the south channel are still 7 ft., and in the north channel 8 ft., while an outer shoal of only 4 to 5 ft. depth, and 1 500 ft. distant covers the entrance. This report states:

"The Yaquina bar is narrow and near land, making its crossing easier than if wide and more seaward. * * * The main sand movement here is from the south. * * * The outer reef is a natural breakwater and reduces the seas on the bar, a most favorable circumstance.

"A proposed north jetty location and south jetty extension are shown on the survey map of 1885 herewith. The north jetty is 3 000 ft. long and projects beyond the south jetty from which it is 1 000 ft. distant."

Up to this date, therefore, the effect appears to have been an advance of the shore line and bar without any increase in depth due to this south jetty, which is stranded between high and low water, although the report of 1887 says: "The new depth is greater by 1 ft. than the best heretofore observed during the same seasons."

Operations on this jetty were resumed in 1886–7, and during the next fiscal year it was extended only 460 ft. In 1888–9 the south jetty was reported as having been extended 4 265 ft., and the tramway started for the north jetty, on which 12 980 tons were placed in 1889–90, and 18 040 tons on the south jetty. In 1890–91 the north jetty was extended 600 ft. In 1891–92 a large part of the south jetty was completed, and the north jetty was extended 840 ft.

In 1900 it was reported that the project of 1881 was practically completed in 1895, comprising the construction of a north jetty 2 800 ft. long and a south jetty 3 748 ft. long.

"It was expected that this work would obtain a depth of 17 ft. at high water, but the results are now somewhat in excess of that depth.

"There is at present, about one-half mile from the end of the jetties, a cresent-shaped bar almost inclosing the entrance and having from 8 to 12 ft. of water over it at low low water. Around the south end of this shoal there is a channel having a least depth of 13 ft. at low tide. This bar has apparently shoaled somewhat since the survey of 1895."

The map accompanying this report shows a limiting depth on the bar of only 10 ft. at mean low water, and, as the original depths were at times from 5 to 10 ft., the maximum depths of 17 ft. at high water have apparently not been increased materially, if at all, as the report admits, while the bar has been moving out toward the reef at least a quarter of a mile.

This project of 1881 was no sooner reported as completed in 1895

Mr. Haupt.

than another Board was appointed to investigate and report "with a view to a project for deeper water." It reported that, "if any further deepening of water could be effected it would only be by prolonging the present jetties," and it proposed to extend the north jetty 2 000 and the south jetty 2 200 ft.,* and to remove some detached rocks at the entrance, at a total cost of $1 025 800. Congress made a preliminary appropriation under this project in June, 1896, but the work has not been commenced and the Board of 1899 does not recommend anything further than the removal of the rock. The total cost of this experiment between 1880 and 1896 was about $688 000, and, in view of the history and results as reported, it is difficult for the writer to discover any improvement as to increased depths over the bar or even the fixing of the channel.

The low-tide single jetty of 1881 was amended in 1888:

> "To raise it to full high water with a length of 3 748 ft. and to construct a mid-tide jetty on the north side to extend in a southwesterly direction about 2 300 ft. and to give an entrance width of 1 000 ft. This plan was further modified in 1892 to raise the north jetty to high-water level and to build five spurs on the channel side of the south jetty to prevent undermining."†

The depths as reported in 1896, were said to have been increased to from 12 to 15 ft. at mean low water, and the project was considered completed.

As the reported depths in 1900 were a bar with from 8 to 12 ft., at low water and a channel depth of 10 ft., it would appear that, as the Board has reported, the bar has shoaled since 1895, and that the claim made that: "These jetties at Yaquina Bay have increased the depth from 7 to 15 ft. at mean low water, and, so far as the records show, without as yet producing any new bar seaward of the jetties," does not accord with the facts as officially reported by the Board of Engineers of 1900.

Considerable space has been devoted to this case, as it is believed to furnish no new evidence of the success of high-tide twin jetties, and it is respectfully suggested that the claim of the author that "for more than seven years, depths considerably in excess of those stated for the project have been maintained," might be modified to advantage. The projected depths, as revised, were 19 ft. at high water. The present map of the survey of 1899 (Fig. 8), made in June and July, if correct, shows the best channel depth to be 10 ft., to which, if the mean height of the tide be added, there results, 17.1 ft., or nearly 2 ft. less than those stated in the project. Moreover, the condition here is apparently not stable, but retrograding; and jetty extensions were recommended to improve the depths, but not applied, as it was thought the commerce did not justify the expenditure at this time.

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*Report of 1896, p. 3242.

†Report of 1896, p. 3241.

Mr. Haupt. The author next refers to Coos Bay, Columbia River and Grays Harbor as illustrations of sites where "the natural conditions are such that one jetty has already accomplished so much improvement that the necessity for a second jetty is not yet apparent." It has been shown, however, that at Coos Head and Columbia River the bars have advanced, and the depths diminished. That Cape Disappointment is regarded as performing the function of a second jetty is admitted, while at Grays Harbor the partial jetty is located to leeward of the channel and gives no better assurance of bar control than the others. It was sufficiently demonstrated by the writer in the discussion of a previous paper,* and need not be repeated here.

Dredging Tidal Entrances.—One other point of importance is raised in this interesting paper. It refers to the methods of improving ocean bars by dredging, and the writer is pleased to find himself in thorough accord with the author when he says:

> "As the forces going to build up the bars are intermittent, but constantly recurring, no temporary expedient, such as dredging, would be of any special value, owing to the extreme likelihood of such work being completely nullified by the effect of a single severe storm."

This is confirmed by repeated experiences on exposed bars.

On the other hand, after reviewing all the several methods of bar improvement, the author of the Report on the Brunswick Bar reaches the conclusion that, for that place, "dredging appears to be by all means the most economical and satisfactory method."

This is at an ocean bar about 4 miles from land and on the borders of the trade winds where the sea is frequently rough, and, while the cost per yard of the material removed is based upon "dredging," the author of that report says it "has been successful as to permanence of the improvement." He appears to have ignored the general disintegrating effects of the large charges (100 lbs.) of dynamite which were used on this bar simultaneously with dredging. It becomes, therefore, an important matter to study the relative permanency and depths secured as the work progressed, the data for which are furnished by the very complete exhibits contained in Doc. 355, before quoted.

Movements of the Thalweg of the Brunswick Bar Channel.—First, as to the original condition, the report says:

> "Prior to 1879 the channel depth across this bar was about 17 ft. at mean low water. Between 1879 and 1889 this channel became obliterated, and the best navigable depth at the latter date was about 13 ft. at mean low water. The present navigable depth is 18 ft. at mean low water."

Speaking of the changes in location of the channel, the report says:

> "Brunswick Bar is an exceedingly slow one to change. The reason of this is that it is not in a region of long-continued storms or high winds, etc." (page 4).

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* *Transactions*, Am. Soc. C. E., Vol. xxxvi, p. 133.

Mr. Haupt.

The experience of the Coast Survey Assistant who, in making a survey, was detained on the bar from December 27th until January 4th, "before the weather permitted a beginning to be made on the work," and the stormy and unfavorable season following, which still further prolonged the work "much beyond the date anticipated for its completion," may be taken as a fair type of the weather at that locality during the winter and spring months. The survey was not finished until April 16th, 1897. It was called for in the previous November, a period of six months.

The improvement of this bar began in 1891 by the use of dynamite, when the best navigable depths were "about 13 ft." Since that time, and up to the end of the survey made in November, 1899, the increase was 5.6 ft., and the cost per foot of depth gained was $45 293.95.* But the author of this report says:

> "The channel now existing at Brunswick Bar has been produced by Nature, aided very materially by ordinary dredging. The useful effect of dynamite has been very small, except possibly to loosen material in some places as an aid to dredging. The cost to the Government of all material removed, whether usefully removed or otherwise, has been $1.13 a yard, more than seven times the cost of ordinary dredging. The channel produced has no advantage of permanence over a dredged channel of similar size and location which could be produced for about one-twelfth of the cost of the present channel."

By "ordinary dredging" here is meant the use of a hydraulic plant with bins.

An analysis of the foregoing conclusions shows that, according to the author, Nature and dredging allied have produced the present channel, upon which the effect of the dynamite "has been very small," yet the channel thus produced by dredging and Nature has no advantage of permanence over a dredged channel which could have been produced for about one-twelfth its cost. Hence, it would follow that the work done by Nature alone must have added eleven-twelfths, or about 92%, to the cost. Therefore, the engineer should aim to eliminate any assistance from Nature, and confine himself to mechanical means to cheapen the works.

As to the permanence of this channel, it is here stated that it has no advantage over a dredged channel, while on another page of the same report it is said of this bar:

> "It is an enormous sand bank which moves and which always moves very positively in one direction."

This being the case, an unprotected, dredged channel would naturally be expected to fill up in a comparatively short time unless protected by a barrier; but the report says of this dynamited channel:

> "It has been quite successful, as to the permanence of the improvement."

From the maps and table on page 11 of the report quoted the data in Table No. 3 have been collated:

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* Senate Doc. 178, 56th Cong., 1st Sess.

Mr. Haupt.

TABLE No. 3.

Map.	Date.	Interval, in months.	Depth, M. L. W.	Gain or loss.	Movement, in feet.	Direction of motion.	Form of channel.	Notes.
A	Jan., 1891	..	13.3	...	000	....	⌒	Lt. Rees, U. S. E.
B	April, 1891	3	13.4	0.1	800	South	⌣	Dynamite began in July and Aug.—1 650 total.
C	Sept., "	5	13.4	0.0	1 150	"	⌣	
D	June, 1892	9	13.7	0.3	500	North	⌒	Hughes, U. S. N.
E	Nov., "	5	14.0	0.3	350	"	⌒	Rees, U. S. E.
F	June, 1893	7	14.2	0.2	100	South	⌒	"
G	Dec., "	6	14.2	0.0	200	"	⌒	Carter's Assist., U. S. E.
H	March, 1894	3	13.9	0.3	225	"	⌒	Garret, U. S. N.
I	April, 1895	13	15.0	1.1	250	"	⌒	Abbot, U. S. E.
J	July, "	3	14.9	0.1	300	"	⌒	" "
K	Dec., "	5	15.0	0.0	325	"	⌣⌒	" "
L	April, 1897	16	16.6	1.6	500	"	⌣⌒	Dredg. without bins, Peck, U. S. C. S.
M	Feb., 1898	10	17.6	1.0	600	"	⌣⌒	Ordinary dredging. Marindin "
N	April, 1899	14	17.8	...	950	"	⌣⌒	" "
O	Nov., 1899	..	18.5	...	1 000	"	⌣⌒	" "

Several features are prominently brought out by this exhibit :

1.—The progressive deepening, increasing more rapidly as the channel becomes more stable.

2.—That at first the bar crest was so nearly level and so close to the ordinary limit of wave disturbance that a few inches of change in its elevation caused great changes in the location of the channel.

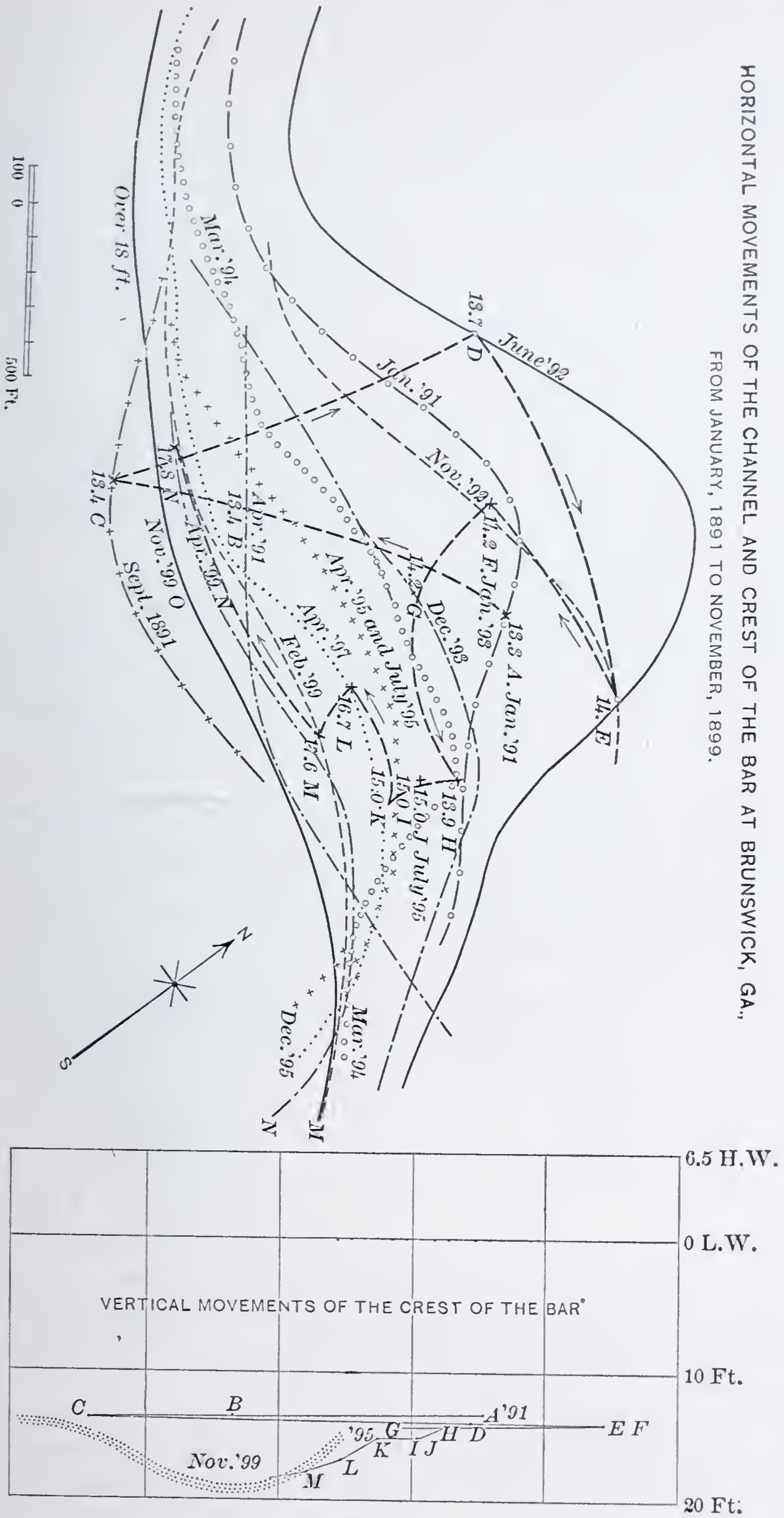
3.—That dredging did not begin until between December and April, 1897, and then it was merely to stir up, but not carry off, the silt. At this date the depths had increased from 13.3 to 16.6 ft., and, by the time the hydraulic dredging and removal commenced, the depth (by interpolation) was about 17.2 ft., showing a gain, due almost entirely to dynamiting, of 3.9 ft. The subsequent increase to November, 1899, is 1.3 ft., but even this was not due to dredging alone, as the report shows that dynamite was used throughout the entire period, at first in 10 and 20-lb, charges, and after August, 1892, in 100-lb. charges.

4.—The greatest change in the position of the channel occurred between September, 1891, and June, 1892, nine months, when it moved 1 650 ft. from its extreme southerly to its extreme northerly limit, due to a change of level of only a few inches on the bar.

5.—From June, 1892, it steadily drifted back to the south, and as the depths increased the movements decreased, while the thalweg became more direct.

6.—The path of the channel is never straight, but always curved; more sharply in the shoaler depths and more gradually as the depths increased. It now assumes the reverse-curve form adopted for the reaction breakwater.

Mr. Haupt



HORIZONTAL MOVEMENTS OF THE CHANNEL AND CREST OF THE BAR AT BRUNSWICK, GA.,

FROM JANUARY, 1891 TO NOVEMBER, 1899.

VERTICAL MOVEMENTS OF THE CREST OF THE BAR

Fig. 9.

Mr. Haupt. 7.—The ratio of depth before hydraulic dredging to that after is 61%, although dynamite was used after as well as before, so that the effort to make it appear that the channel was secured by Nature, aided by dredging, is, to say the least, misleading.

8.—The breadth across the bar is about ½ mile, and it remains practically constant, while the points of ingress and egress are not shifting. The bar, therefore, has not advanced seaward, although the location of the point of least depth has been changing as the depth increased.

The effort of Nature is to fill up the channel by this traveling bank "which moves very positively in one direction," as the surveys also show. The cross-section also confirms this statement, as the report says:

> The present channel "is about 300 ft. wide, and the side slopes on the south are about 1 ft. in 100. The north slope is steeper—about 1 ft. in 30."

These slopes indicate the direction of movement of the bank to be southerly. (See Fig. 9.)

The form and permanency of the channel, therefore, must be attributed to the use of dynamite in enabling the currents to select, create and maintain a channel along the line of least resistance, and they all tend to demonstrate that had a straight channel been dredged across this bar at any point it would not have been adapted to the natural conditions and could not have been self-maintaining. This is the general experience elsewhere.

But there is another exhibit in this report which is of greater importance, because, from it the estimated cost ($1.13 per cubic yard) of material removed was derived.

It is given on page 14, and purports to show the volume of scour and deposit within certain areas, in the vicinity of and including the channel, for strips varying in width from 400 to 2 000 ft., and for the years from April, 1891, to November, 1899. From this it appears that for the following widths the quantities for a length of 4 680 ft. are:

400	ft. wide	166 892	net cubic yards.
600	"	209 598	" "
800	"	218 260	" "
1 000	"	191 420	" "
1 200	"	176 000	" "

From this it appears that the strip 800 ft. in width shows the greatest net gain, and as the total cost, as stated in Senate Doc. 178, 56th Cong., 1st Session, is $253 646.15, this, at $1.13 per yard would require the removal of 224 465 cu. yds., so that the estimate is apparently based upon the net displacement of material during the entire term. But the author says that a channel as good as the present one could have been secured by the dredging of 125 000 cu. yds. at a total cost of $18 750.

If so, is it not a severe reflection upon his predecessors that it has never been done, either here or anywhere else? Mr. Haupt.

The error of this calculation arises from considering the quantity of material in a given area as a constant, and assuming that the portion excavated from the channel is in part, at least, deposited over its flanks, constituting merely a change of form without material change of volume. It produces the anomalous results, as shown in the first part of Table No. 3, viz., that for every width considered in a strip of 6 370 ft. in length, between the years 1891 and 1897, there was a net fill varying from 76 733 to 208 416 cu. yds., and yet in this time the channel was shifting, earlier ones being filled and later ones opening, with a gain in depth of channel of 3.3 ft. On this basis of payment, the contractor would be a debtor instead of a creditor.

It is, therefore, unjust and inaccurate to measure quantities in place, where a bar is in motion and when superfluous material is being constantly supplied to replace that which has been removed.

The writer knows of instances of dredged cuts having refilled within a few months of the completion of the contract. Had the material been measured in place instead of in the scow, the contractor would have been ruined, and so must everyone be who undertakes to base his bid on net measurements before and after execution.

It follows, therefore, that any conclusions based upon the cost of dredging on a moving ocean bar at even 15 cents per yard, with the hope of securing and maintaining a permanent channel, must end in disappointment and failure. The record of experience is no doubt of more value than many opinions, and that shows that the cost of obtaining depths by any of the existing auxiliary methods is about ten-fold that of the method pursued at Brunswick, for each foot of depth actually secured.

This demonstration of the use of dynamite as an agent in assisting Nature has, therefore, proved to be remarkably successful at the Brunswick Bar, which has not shoaled materially in the past two years, during which no work has been done. A careful analysis of the various methods used in the United States during the past thirty years shows that they have not fulfilled the conditions laid down for them.

The two-jetty plan of submerged jetties as designed for tidal estuaries has been abandoned, and at Charleston, where they were constructed at a cost of about $4 000 000, the fallacy of admitting the sand over the flanks only to be carried seaward at ebb to supply the bar is fully demonstrated. Low-tide jetties have been raised to mid-tide and subsequently to high water to control the sand movements and defend the channel, but, as a rule, the foreshore advances and the bars still move seaward retaining the same depths except as they are increased temporarily by dredging at large annual cost for maintenance;

Mr. Haupt. while the tidal energy is reduced by the partial dams built on the flanks of the entrances.

When single jetties have been attempted they have been constructed, almost invariably, first on the wrong side of the channel, where they have created deposits in it and a more rapid advance of the bar seaward; and, ultimately, a second jetty has been required to restrain the drift, but after it was too late and the original entrance was closed, as at Cumberland Sound. These expensive experiments, of which there are so many on record, do not seem to have led to any modifications in practice, for still it is recommended to build the single jetty on the leeward side of the channel, where it must dam it up; and the method of tentative experimentation goes merrily on.

In the discussion of this valuable paper, Captain Black says truly that hindsight is better than foresight, but in taking his bearings upon the retrospect he seems to have gotten on the wrong trail, which would lead to some erroneous deductions.

First.—The first of these is that although certain works were designed thirty years ago by officers, now deceased, it is found better to "complete them on the original lines rather than make them conform more closely to the plans which more recent experience has shown to be best." Most engineers, on finding the line too expensive and not well adapted to its purpose, would have changed the location for the best and most economical by taking a new "departure" and getting out of the rut.

Second.—Attention is confined chiefly to the movements of sand and the causes producing them, while the tidal volume and other important factors are ignored. No correct conclusions can be reached unless all the elements are considered, and they are many and variable. They have been set forth already in previous publications.

In describing the formation of the "crescent-shaped bar," it is said that it is "pushed out until the ebb currents have a chance to spread and lose their force," and "the ebb has joined to it the drainage of the area of the interior." In many cases the interior drainage is so small that it is less than sufficient to provide for the evaporation in the large interior lagoons or bays receiving it. It is therefore negative, and hence the entire maintenance of the channel is made to depend upon the tidal energy, regulated by protecting works; and, as the bar itself is the location where the ebb currents spread the most and fail to maintain their velocity, that is where the assistance should be applied "to prevent the water of the ebb from spreading and losing its force." It has been successfully done by local work, which does not interfere with the ingress of the tide, upon which alone the results are dependent. The jetties need not be continuous from the shore out across the bar in tidal inlets. Such construction has invariably been found to be unsatisfactory. Captain Black's remarks are apparently confined to those cases where there is a river emptying directly into the sea, in which cases a continuous single jetty, properly located, would be most effective, because the material of the bar is derived mainly from within, and not from the littoral drift. This river sediment is vastly greater in many instances than that from outside, and, if two jetties are built, the deposits must occur either beyond them, in the sea, or above them, in the river, thus raising its bed and its flood plane; in either case producing injury to the navigable channel, and requiring constant dredging. See the records of the South Pass of the Mississippi River. Mr. Haupt.

Third.—Attention is called to the unreliability of maps, as representing general conditions, because of the frequent changes produced by storms. But, as the map is supposed to be the record of the facts, at the time of the survey, it is the only reliable basis for study and deductions, and when a comparison of a number of maps shows a prevailing direction of movement it is certainly a reasonable inference that such representation is correct.

We must not discredit our data, else we have no basis for our deductions. The large number of surveys, by different authorities and under variable conditions, at Brunswick Bar, all showed progressive deepening during the use of dynamite and none before it; hence, the deduction is justifiable that the effect was due to that cause, though there are engineers who assert that it was not, but that "Nature" had come to the rescue. How or why, they do not attempt to explain, but rely on the simple negation.

If maps do not represent the general conditions, then, too strenuous an interpretation should not be placed upon them in deciding upon the fulfillment of a contract, and especially when weather conditions are such that the surveys cannot be completed until about six months have elapsed after the required depths were secured. In consequence, the shoaling of a few inches, in places, retarded payments for more than a year, although the terms of the contract were substantially and honestly complied with, and the channel had been in use by vessels of the requisite draft.

Fourth.—In considering the location of a single jetty on the South Atlantic, Captain Black concludes "that one jetty will rarely do its work," but he cites no actual precedent. He theorizes upon imaginary onditions, and does not realize the ultimate resources of the engineer n arresting littoral drift before it ever reaches the jetty, should it be necessary. He assumes also that "there is nothing to prevent the preading before the working point is reached," forgetting that a current ejected from a coast between walls of water maintains its energy for considerable distance, and that there is frequently a large excess, so hat the utilization of only a portion of it may suffice for navigation purposes across the bar. After considering the case of a jetty on the orth side to impound the sand, and then on the "south, concave to

Mr. Haupt. the current, in order to hold it," the conclusion is reached that "in both cases results are disappointing," as "could be illustrated from the history of both the St. Johns River and Galveston improvements."

While it is true that in both these instances the results were disappointing in the extreme, the hindsight is again defective, as in neither case was a single concave jetty built, but, on the contrary, in both cases two convergent straight jetties were constructed; hence, no deductions from them can be applied to a concave jetty located on the correct side of the channel. They have served their purpose in teaching what to avoid in future. These disappointing results were anticipated and reiterated by some of the civil engineers employed on the works, who were rewarded by being dismissed.

A continuous concave jetty, however, was built at Aransas Pass by the Government, was an acknowledged failure, and was abandoned; but a detached, concave breakwater built on the bar by private parties was a pronounced success, although only partially completed. What constituted this difference between success and failure at the same inlet—and at one-half the cost?

Mr. Black. W. M. Black, M. Am. Soc. C. E.—As age increases, the engineer, of all men, can bear witness the more from his heart that hindsight is much more sure than foresight.

In considering the Charleston and other jetties on the Atlantic Coast, mentioned by Professor Haupt in his comprehensive discussion on this interesting paper, it should be remembered that they were designed about thirty years ago, and that it has been found advantageous to complete them on the original lines rather than make them conform more closely to the plans which more recent experience has shown to be best.

Much has been written recently concerning the efficiency of jetties on ocean bars. It appears to the speaker, however, that in the discussions there are several principles which are frequently lost sight of. Let us take, first of all, the sand movement. What produces the bar in the first place? The sand is not banked up opposite the mouth of a river originally; it comes from somewhere. On the South Atlantic Coast it is known that there is a strong and almost continuous sand movement. This has been shown conclusively at the mouth of the Cape Fear River, N. C., and at the mouth of St. Johns River, Fla., for example. At the mouth of the St. Johns River, at one stage of the jetty construction, a great deal of sand was impounded on the north side of the jetties, and a portion of it passed around the jetties and was impounded on the south side. A summer resort had been located at Pablo Beach, about 6 miles below, and the result of this impounding of the sand at the jetties was an erosion of the coast at Pablo Beach to an extent sufficient to cause alarm to the cottagers. As soon as the sand had accumulated in quantity sufficient to fill the basins formed by the jetties, the movement along the coast was resumed and the erosion at Pablo stopped. Mr. Black.

Along all our flat Atlantic Coast, sea bathers know that after a storm the foreshore for some distance out is in furrows. After a storm a beach which has been perfectly flat before the storm shows a number of deep channels running parallel to the coast. During a northeast gale, the waves approach the shore from the northeast on a line oblique to the coast. As they reach shoal water they are wheeled, as it were, partly parallel to the coast, but never entirely so. As soon as a wave gets into water of which the depth is about twice its height, the bottom of the wave is stopped; a portion of its energy is transformed into a motion of translation of the water; the bottom of the ocean is stirred up and the sand is carried ashore. When the wave finally breaks, more sand is stirred up. The sand is carried upon the beach with the wave wash which moves obliquely up the beach, turns and runs back, not opposite the point at which the wave struck, but further south. At the same time the whole of the ocean is in a measure backed up against the shore. The level is actually raised. In the harbors on this coast the flood tides are frequently made much igher, and sometimes the ebb is entirely imperceptible for twenty-our hours.

These two causes form, during every northeast gale, a very strong urrent close inshore, running in the direction of the line of least esistance, which, under a northeast gale, is generally to the south, outh of Central New Jersey. The sand eroded in one place is ordiarily replaced by that eroded to the north of it; but if any part of it s impounded, the invariable result is to make evident the cutting elow. In making groins for building out the coast, the first result is lways a cutting—on the South Atlantic Coast to the south of the roin, with a fill on the north of the groin. As the fill increases, the and on the north works around to the south. This sand movement the cause of the wind and wave bars, and it is natural to suppose at that action does not cease, but is continually recurring. The eight of the bar is a function of the currents and of the storms. hen it gets too high the top is swept off and carried along; when o low it is filled up. At some places that movement is very rapid; other places it is very slow; so that the condition even of sand bars our harbors may be very stable or very unstable, and whether it is able or unstable can only be determined by a study of the local contions. At Pensacola, for instance, the bar is of heavy, coarse sand, d is quite stable. At the mouth of the St. Johns River, and the outh of the Cumberland Sound, the bar is of very light sand and is ry unstable.

Opposite an opening in the coast there is a deflection of what may termed the sand current, seaward, because the ebb has joined to it

Mr. Black. the drainage of the area of the interior, and leaves the coast line, directed by the banks of the interior waterway, as a definite force. As a result, the deep-water channel of the interior waterway is conserved for a longer or shorter distance seaward from the shore line, and the sand flow along the coast is pushed out, making the crescent-shaped bar of which so much has been said—pushed out until the ebb currents have a chance to spread and lose their force.

Now, in a bar of that kind, it is evident that there are two distinct parts in the work of its improvement. The first is to cut through the obstructing bar; the second, entirely distinct from the first, is to keep it cut through; for it is evident that the forces which formed that bar first will work to maintain it. It is also evident that that movement along the coast, or in the direction of the resultant storm action, only extends to a certain depth, and that sand can be piled up to that depth with a certain degree of stability. As soon as this depth is decreased the wave and current action is bound to move the deposit along in exactly the same way as before. As stated, that depth is a function of the wave height. On the Pacific Coast the shores are very abrupt and the waves are high—as high as 30 ft.—and breaking in 6 to 8 fathoms, as stated by the author. There the action would take place at greater depth than on the Atlantic Coast, where the water is much more shallow and the foreshore much flatter.

The first problem that must be solved when jetties are to be used is how to guide the ebb currents so as to direct their force to and at the point where needed; in other words, to prevent the water of the ebb from spreading and losing its force before it reaches the bar. For that reason, in almost all cases, it is essential to hold the jetties close together to some point. In the case of converging jetties, the shore ends have effect on the direction of the current only through the sand impounded between them and the channel. When the channel near the shore is stable, this form of jetties is good, otherwise it is not. Where work is to be done in a bar, the head of the outflowing water must be held until the bar is reached, and for this it is evident that the jetties must be continuous from the shore out. Otherwise, there would be spreading of the channel flow close inshore, with a loss of effective force.

Much has been said about a jetty to the leeward and a jetty to the windward, and yet if it is considered that the head must be conserved until the point for work is reached, it is evident that one jetty will rarely do its work. Taking the sand movement on the South Atlantic Coast from north to south, if the jetty is placed on the north side the sand will be impounded for a certain time, and the currents, which in general leave the shore at right angles to the coast, will be continued in direction. But there is nothing to prevent the spreading before the working point is reached, which is frequently a mile from the coast.

Mr. Black.

If the jetty is placed on the south, concave to the current, in order to hold it, when the sand movement is sufficiently marked, making the bar obstinate, as it were, shallow false channels will branch out to the north inside the channel bar, and the effective force will again be lost. In one case the sand is kept away; in the other case the current is conserved a little better; but in both cases results are disappointing. Did time permit, these statements could be illustrated from the history of both the St. Johns River and Galveston improvements.

Suppose the jetties in place and the channel scoured out. Nothing has been done to stop the sand movement. It makes no difference how high the jetty is built. In course of time, sufficient sand will be impounded to renew the sand movement across it and around its end. Building the jetty high with the hope of impounding all the sand that is going to move in the next fifty years seems rather futile, and does not appeal to the speaker.

It is believed that in all the harbors on the Atlantic Coast, and to a less extent on the Pacific Coast (because the movement there seems very much slower than on the Atlantic Coast), it is necessary first of all to have the jetties so placed as to cause the currents to bore through the bar, and to maintain the channel in a fixed position, so that it cannot shift under storm action; and then it is further necessary to take care of the constantly incoming sand exactly as has been necessary in the very much smaller jetties of the north of France. The amount of sand coming in year by year can be measured. At the mouth of the St. Johns it was measured quite accurately.

The jetties hold the channel. The annual accumulations must be removed by dredging, and if, in the work of cutting the channel originally, dredging be used, there will be little or no movement of the bar seaward. The dredging can be done between the jetties, or on the side from which the obstructing movement comes, as is frequently the custom in France, making a basin in which the sand or shingle will be deposited, and in that way not interfering with navigation. The channels in our country are ordinarily so broad that a dredge can be worked in them efficiently. In the French jetties, the channel is so narrow that a dredge cannot operate there without interfering with navigation.

There has been something said in this discussion about the comparison of maps. Anyone who knows these unstable bars very well knows that unless a map is made about once a month, map study may be very misleading, because the conditions change radically from month to month. Usually, on the Atlantic Coast northeast gales begin in September and last until April. In the summer time southeast gales are not rare. The map will show the results of the last storm action, not necessarily of the resultant storm action, nor the normal condiions. So it is dangerous to draw close conclusions from maps taken at long intervals.

Mr. Black. In regard to the use of dynamite at Brunswick, the speaker's deductions from the published reports are quite the reverse of those formed by Professor Haupt.

To the speaker, it seemed that the use of dynamite has been absolutely of no avail. The effects of the stirring up of sand by any means —by propeller dredging or anything else—is well known. There is no difficulty at all in getting any depth wanted by propeller dredging. The only difficulty is that the depth is lost in 20 or 30 ft., because it requires quite a high velocity and constant agitation to keep sand in motion. It must be stirred up and then kept moving. Propeller dredging has been resorted to very efficaciously in a narrow bar bounded by deep water, but over a broad bar, any local effect of that kind is bound to be local, and what is gained in one place is lost in another. The current will not carry sand for a long distance. Captain Gillette's paper, to which Professor Haupt alludes, is of great interest. Captain Gillette recommends the use of dredging in the Brunswick bar, believing that the channel will be sufficiently stable. Perhaps it will; perhaps it will not. In the absence of intimate knowledge of the local conditions, it is impossible for outsiders to judge.

The conditions on the Pacific Coast at Coos Bay seemed to the speaker, in reading the report and in looking at the maps, obscure. The resultant storms along that coast undoubtedly are from the south. The movement of sand at the mouth of the Columbia River is undoubtedly from the south, and yet the formation at Coos Bay would seem to show a local movement of sand from the north. That might come from some local current or wind action due to a bight in the coast. During the past year many theories have been advanced relating to the disposal of the sewage of the City of Havana. Everybody knows that the Gulf Stream flows between the Florida Reefs and the coast of Cuba from west to east, and flows with much velocity, and it is taken for granted that there is a current from west to east on the north coast of Cuba. As a matter of fact, the City of Havana is in a bight, and the current there is almost invariably, with very few exceptions in the month, decidedly from east to west. So that where there is a general movement along a coast in a certain direction, if there is a bight or local cause of that kind, an eddy is very apt to be formed, and the local movement may be in exactly the opposite direction. From looking at the maps, the speaker judges there must be some local sand movement at Coos Bay, a movement close inshore from north to south. These things are only mentioned in order to emphasize the fact that it is impossible to judge of the conditions at any point from maps taken at long intervals and without an intimate knowledge.

Mr. Ripley. H. C. Ripley, M. Am. Soc. C. E. (by letter).—The author gives an interesting description of the general physical characteristics of the North Pacific Coast and of the local conditions found at Coos Bay before work was commenced. He also gives a very fair diagnosis of the case and describes the treatment to be applied, and, so far as the work has been executed, he seems to regard the results as eminently successful, although he deems it probable that the south jetty will have to be built before the undesirable fluctuations in channel depth can be controlled. However, he apparently realizes the possibility of effecting an improvement by means of one jetty, where he says: Mr. Ripley.

> "It was clearly evident that the north jetty would certainly be necessary, but, before commencing work, it was not so plain that the south jetty could not be dispensed with."

It will be interesting, therefore, if he will explain how the north jetty could be expected to intercept the sand drift from the south, which is the prevailing littoral movement, and why he should expect results at Coos Bay different from those at Charleston, S. C.; Cumberland Sound, Ga. and Fla.; St. Johns River, Fla.; Galveston and Aransas Pass, Texas, and many other places on the Atlantic and Gulf coasts where there have been expended many millions of dollars in experiments of this nature.

If the author will put in the 22-ft. contour of depth on the map of the August, 1899, survey (Fig. 5), he will find an area of deep water lying to the north of the north jetty having a length of over 2 000 ft. and a maximum depth of 37 ft. Had the south jetty been built first, this deep-water area would have been in the channel instead of behind the jetty, and, with the channel defended from the sand movement from the south, an increased channel depth of considerable degree of permanence would have been maintained. It seems, therefore, that the north jetty was certainly not the one to build first, and, if either jetty could be omitted entirely, it would be the north jetty that could be dispensed with.

If we examine a little more into the details of the changes, we find that from 1885 to 1899 the bar, as shown by the 18-ft. contour outside, has advanced 2 000 ft., and from 1894 to 1899 the channel width, between the 18-ft. contour and the jetty, has diminished from 800 ft. to 425 ft. and the south shoal has completely overlapped the entrance channel.

The author states that, with one exception, in November, 1899, when the depth shoaled for several weeks to 9 ft., due to a long and severe southwesterly storm, a depth of from 18 to 22 ft. has been maintained for seven years. It will be seen, however, by reference to the map of the 1899 survey, that a vessel, to avail itself of the best depth of water, would have to cross the bar broadside to the sea and make a right-angle turn near the outer end of the jetty before making the entrance —a feat quite impossible of accomplishment except for the shortest vessels and when the sea is comparatively smooth. But he, nevertheless, assures us that, thus far, this improvement has been eminently

Mr. Ripley. successful. When it is remembered, however, that the most important function in determining the commercial value of a port is the uniformity of available depth, and that a fluctuation of as much as 13 ft. is possible here, it is not so apparent wherein this work has been so eminently successful.

That the work has produced important changes, there is no gainsaying. It is equally true that the average depth of entrance has been increased. But these changes have been largely subject to the caprice of wind and wave, and have in no sense been under the control of the works. The advance of the bar will increase the cost of a second jetty, and the complete accomplishment of a satisfactory improvement will be more expensive than had this work not been done at all.

The author, however, seems to realize the real essentials to success when he says:

> "If works can be devised to prevent the encroachment of the sand on the channel and at the same time prevent the divergence and dissipation of the effect of the ebb tides, by confining and directing these tidal currents at a selected point of the bar, improvement may be confidently expected."

And it is equally apparent that the works thus far have not in any measure met the conditions here imposed.

If the author had read and appreciated the valuable writings of L. M. Haupt, M. Am. Soc. C. E., and others, on this subject, read before numerous scientific organizations of this country within the last fifteen years, the discussions before this Society by its members, the valuable papers read at the meetings of the International Navigation Congress, and if he had seen the results of a single jetty properly located, at the Malamocco entrance to the Harbor of Venice, and of the remarkable results from the reaction or curved breakwater, partially completed at Aransas Pass, Tex., he would have realized the possibility of fulfilling the foregoing conditions and thereby effecting a complete and permanent improvement by means of a single curved structure, either detached from or attached to the shore, and at a cost of from 25% to 50% of the cost under the adopted plan.

The writer's experience with brush mattresses agrees with that of the author. It was found on the Texas coast, as long ago as 1885, that stone made a much better protection from scour and undermining than brush work, and, where the teredo operates, it is much cheaper than brush, even when stone costs as much as $4 to $5 per ton.

Mr. McKinstry. C. H. McKinstry, M. Am. Soc. C. E. (by letter).—The jetty at Coos Bay is a straight jetty built on the lee side of the entrance and connected with the shore. The jetty at Aransas Pass, to which reference has been made in two of the discussions, has a trace which is a "compound and reverse" curve, is built on the windward side of the entrance, and is detached from the shore.

Mr. McKinstry.

The first is an example of the "single lee" jetty system; the second is a particular case of the "single windward" system.

The writer offers a few remarks on these two systems, with particular reference to conditions existing on the South Atlantic and Pacific Coasts of the United States.

A few preliminary remarks on littoral drift, and the effect of groynes and jetties upon it, may conduce to clearness.

*Littoral Drift.**—Surf raised by winds blowing along shore or obliquely on shore is the principal cause of littoral drift. The relative effect of this and of other causes is well brought out in the discussion following Mr. W. H. Wheeler's article,† in which the proposition is advanced that the principal agent in the transport of material along shores is the "wave-action of the flood tide." Strong littoral currents, pure and simple, and strong littoral tidal currents increase the transporting power of the surf when they coincide in direction with the wind producing the surf, and decrease it when they are opposed to that direction; but, in general, their sphere of action is not close in shore, but is in deep water.

There are no littoral currents, strictly so-called, along the South Atlantic Coast. Along the coast of Oregon and Washington there is a northward littoral current, an eddy from the Japan Current, but it is of slight velocity.

Along the coasts of Georgia and Florida there are littoral tidal currents, northerly during flood and southerly during ebb, due to the direction in which the tidal wave enters the great bay lying to the west of a line joining Hatteras and Canaveral. But these currents are of slight velocity, and are checked and even reversed by strong storm winds. The littoral tidal currents on the Pacific Coast are likewise of slight velocity.

In other words, the drift on these coasts, as on the coasts of tideless seas, is due almost wholly to surf raised by the wind.

The waves break and run in obliquely, while the receding water flows down the beach in a line nearly perpendicular to the shore. The effect of this zigzag motion of the breaking waves is a current which at times is of great velocity; strong enough often to sweep bathers off their feet. This is General Gillmore's "surf-current." Shield describes it as the "run, or set along shore, resulting from wave-action."‡ The drift of the water to leeward at the extreme inner edge of the broken waves is too well known to need remark. From the shore out to a depth depending on their size, the waves stir up material from the bottom and keep it in suspension, and it moves along

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* The movement of sand by wind, above the water line, will not be touched on.

† "Littoral Drift: in its relation to the Outfalls of Rivers, and to the Construction and Maintenance of Harbours on Sandy Coasts."—*Minutes of Proceedings*, Institution of Civil Engineers, Vol. cxxv, 1895–96, p. 20.

‡ "Principles and Practice of Harbour Construction."

Mr. McKinstry. with the currents. On many coasts the discoloration of the water, due to this suspended material, is distinctly observable. Besides producing surf more or less heavy, a strong wind blowing along shore or obliquely on shore produces a littoral current, which, to distinguish it, may be called the "littoral storm current."

Within a wide zone, the movement of material is due to the littoral current; near shore it is caused by the surf current, while along the edge of the water it is caused directly by the broken waves. By the first two the material is carried in suspension; by the third, it is pushed bodily along. Doubtless, however, the surf current is often strong enough to roll material along the bottom as well as to carry it in suspension. In a cross-section at right angles to the shore the amount of material in motion varies from a maximum close in shore to zero at the limit of wave disturbance.*

On the South Atlantic Coast the drift is to the north in southerly winds, and to the south in northerly winds, but there is a strong resultant drift to the south due to the fact that the prevailing storm winds are from the northeast.

At Humboldt Bay, Cal., there is said to be no well-defined resultant drift, the movement to the south during the summer about counterbalancing that to the north during the winter.

At the mouth of the Columbia River the resultant drift is to the north.

Groynes and Jetties.—One effect of a groyne is to cause, during an alongshore storm, a strong current past the pier-head. A "cause of acceleration of tidal currents" is "that resulting from capes or headlands ponding back the water. At such points the main body of water to seaward is, by its inertia, slow to give way * * * to these irregularities of coast line, the result being that the passage or transfer of the inshore water from one side of the promontory to the other is obstructed."†

At Ymuiden, as Shield goes on to say, the building of the mile-long piers increased the current from its original velocity along that coast—2 to $2\frac{1}{2}$ knots—to from 3 to 4 knots past the harbor mouth.

Our jetties produce the same effect upon the littoral storm current, as is made evident by the scouring of "pot holes" ahead of advancing jetties, and the resulting necessity of building long lengths of foundation ahead of the main work.

The existence of this accelerated current past the pier-head points to the advisability of curving the jetty off to leeward in order that the issuing harbor current may merge with this cross-current with a minimum of interference and disturbance.

Another effect, of building a groyne on a shore along which there

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* The foregoing outline of the transporting action of the waves and of the "littoral storm current," is taken largely from *Engineering* for August, 1893.

† Shield.

Mr. McKinstry.

is a movement of material, is an advance of the foreshore on its windward side. Whether there will also be a deposit in the lee angle depends on many circumstances, as, for example, on the strength of the winds that cause a littoral current and surf in the opposite direction to that of the prevailing drift, on the depth of water into which the groyne extends, and the velocity of the littoral storm current past the end. There has been an enormous deposit in the lee angle of the lee jetty at the St. Johns, and at other South Atlantic harbors.

It is believed by some that the most severe storms do not cause these deposits in the weather angle; but that at such times the deposits are cut away, the accompanying high tide and heavy surf producing powerful scouring undercurrents.

The building of a groyne or jetty does not, of course, stop the flow of the main portion of the littoral storm current and its suspended sand, but simply deflects it seaward. But it does intercept, for a time at least, the sand moved along by the waves and by the surf current. As a dam suddenly thrown across a stream would stop the flow of the water until the pool had risen to its crest, so a groyne built out into deep water stops for a time the flow of the river of sand traveling along the beach. Opinion is divided as to the extent to which the weather angle will fill up and the extent to which deposits will form on the ocean floor in the neighborhood of the pier-head. It has been held* that the "quantity of drift is limited," and that if the groyne be built into deep enough water, the drift "may be entirely stopped or its movement controlled." The author of these propositions considered that 4 fathoms was a sufficient depth, meaning, it must be, not that the drift would be permanently stopped at the groyne, but that after a certain amount of deposit had taken place in the weather angle the drift would be diverted into deep water and there dissipated. Experience at such places as Madras, Colombo, Malamocco, Newhaven and Ymuiden indicates that after a time the accretion in the weather angle and the advance of the foreshore become extremely slow. Cessation of the advance of the foreshore marks the beginning of the movement of drift past the groyne. What becomes of this drift? If it should be deposited over a comparatively small area in the neighborhood of the pier-head the growth of shoals in that neighborhood would be rapid. In certain of the cases mentioned the growth of such shoals is imperceptible and in the others very, very slow. From this it is plain that, under favorable circumstances, jetties, if long enough, will deflect the drift into deep water where it will be carried away by deep-water currents or else deposited over such a large area that the formation of shoals may be prevented by an amount of dredging not prohibitively great.

The time required to fill the weather angle depends upon the

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* *Minutes of Proceedings*, Institution of Civil Engineers, Vol. cxxv, 1895–96, p. 2.

Mr. McKinstry. quantity of sand moving along the coast and upon the length of the jetty and the depth into which it extends; curving the end of the jetty off to leeward increases the area over which the drift, if it be not carried away by deep-water currents, will be deposited; and an outflowing harbor current does much to deflect still further seaward the current of drift already deflected by the jetty, thus enlarging the area of deposit and tending to dissipate the drift.

At Port Said, when the drift began to deposit across the entrance, the engineers in charge removed sections of the upper part of the west breakwater to allow the drift to deposit in its lee; these deposits being removed from time to time by dredging. They preferred to deal with the drift in a place where dredges could work with but occasional interruption rather than in an outer bar. This expedient should be less necessary at an entrance having an extensive backwater and a considerable rise and fall of tide than at a place like Port Said. Gaps, or low places near shore, have been left in several weather jetties in the United States, but not for the purpose for which they were made at Port Said.

The Single Windward Jetty.—The earliest description of the concave windward jetty that the writer is aware of is contained in Mr. W. A. Brookes' treatise.* Says Wheeler, in "Tidal Rivers":

> "Mr. Brookes also contended that in training a tidal river there is an advantage in giving a preponderating direction of the stream to one side of the channel by rendering it slightly concave. By this means he contends that a greater depth will be maintained in the channel at low water than in a straight channel; that, in training work carried out in sandy estuaries, a single concave training wall will be frequently found sufficient to maintain the channel in one course; and that piers at the mouths of rivers should always effect their junction with the sea by a concave pier on the windward side, by which means the outer division or convex side of the pier would shelter the interior of the channel from the prevailing gales, and prevent the range of the waves running along the face of the pier."

Elsewhere, in "Tidal Rivers," the theory of the action of the single windward jetty is thus explained:

> "In determining the position to be given to training walls in estuaries where they discharge into the sea, the direction not only of the flood and ebb tides and of the prevailing winds must be considered, but also the amount of material that is transported along the coast, and the direction from which it comes. In some cases where there is much littoral drift, especially of shingle, the outfalls have been driven considerably to leeward. In such cases Nature appears to indicate that the water should be directed into the sea by a curved channel having its convex side presented to the direction from which the material is travelling, and that the training should be so designed that it may be extended further out seawards as the shore grows up with the accumulated material. * * * Where one stream joins another, the best direction for the junction of the tributary is by a gentle curve tangen-

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* "Improvement of the Navigation of Tidal Rivers," 1841.

Mr. McKinstry.

tial to the main stream. If this rule were applicable to tidal channels entering the sea, the outfall should be by a curved channel leading in the direction of the main set of the flood tide* along the coast. * * * It may be accepted as correct that, * * * the training walls of rivers, * * * to be successful, should never terminate in shallow water. * * * Where training walls have not been carried out into sufficiently deep water, their effect has been short-lived. Acting as a groyne to stop the travel of the littoral drift, this has rapidly accumulated at the back, and then found its way round the end into the mouth of the river, forming shoals or a bar. Where the pier reaches the level of deep water, the sand or shingle is kept in continual agitation by the effect of gales and the tidal currents, and is either drifted past the entrance or out into the deeper part of the sea. * * * There are cases where a single curved wall, running out from the shore line, has been sufficient to maintain a channel in the direction required. Such a wall placed on the windward side of the channel. * * * and presenting its convex side to the line of drift, if carried sufficiently far out into deep water, will give under favorable circumstances a permanent direction to the flow of water, and afford protection to the entrance from the prevailing gales. The jetty, acting as a groyne, will at first collect the littoral drift in the angle between the pier and the shore, but after this is filled up, the direction given by the convex form of the outer end of the jetty will carry the drift beyond the entrance and into the deep-water currents. The flood tide," (read "littoral storm current") "working round the end of the pier-head into the channel, as it does in the case of the natural pier at Spurn Point in the Humber, will tend to maintain at that point deep water, and prevent the deposit of the littoral drift and the formation of a bar. The ebb current running along the concave side of the jetty will maintain the deepest water along that side of the channel, the flood tide setting up also along the line of deepest water. A uniform and deep channel may thus be maintained. If the line of direction be well chosen with regard to existing circumstances, a single wall will therefore be sufficient to maintain a channel in a uniform direction and preserve deep water. There are several examples where single walls thus carried out have been successful."

Certain of the matters brought out in this extract deserve more particular mention:

1.—"A single windward jetty will often be sufficient to fix an entrance channel."

This is the contention of Professor Haupt, with respect to the reaction breakwater.

He states† that the Aransas Pass jetty was "so adjusted, with reference to the axis of discharge, as to receive the same tangentially," but, as is clearly pointed out by Captain Gillette, in the Report on Brunswick Bar,‡ the axis of discharge owes its position to the Nelson jetty. When work began at Charleston the main channel was parallel to the coast, and the bar at its outer end was 5 miles from the harbor entrance. Let one attempt to adjust a reaction breakwater to these conditions. If

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* To adapt this to conditions at United States harbors, for "flood tide" read "littoral storm current."

† *Transactions*, Am. Soc. C. E., Vol. xlii, p. 492.

‡ House Ex. Doc., No. 355, 56th Cong., 2d Sess.

Mr. McKinstry. placed on the bar and adjusted to the axis of the main channel, it would have to be some 5 or 6 miles long to prevent the channel from breaking out to northward of it. If adjusted to the axis of one of the minor channels, only a small portion of the ebb and flow would be controlled. Similarly, with a Brookes jetty. The necessity of a lee directing jetty in connection with the concave windward (Brookes) jetty, proposed by Professor Haupt for the improvement of the Southwest Pass, is also plainly shown in Captain Gillette's report.

In fact, in order that the concave jetty may do the work expected of it, there must be something on the lee side of the entrance, either a natural bank of the proper shape, or else a jetty, to direct the current into the concavity of the windward jetty.

Accordingly, in existing cases, these supplementary jetties are found to vary from short jetties, like the Nelson jetty at Aransas Pass and the Arenas mole at Bilbao, to jetties perhaps half as long as the main structure, like the south jetty at the Malamocco entrance.

Swinemunde is an example of a complete reversal of this arrangement, for there the longer or main jetty is on the lee side of the entrance, and the windward jetty is convex instead of concave to the channel.

Strictly speaking, the Aransas Pass improvement is not a single-jetty improvement, in spite of the claims of its designers. It is inferable from Mr. Ripley's words* that he regards the Malamocco entrance as such an improvement. He cannot, of course, be unaware of the existence of the south jetty at that place; he must mean to deny to it all share in the improvement effected.

2.—It is advantageous to present a convex curve to the direction of drift. At the same time, a concave bank is thus afforded to the currents in the entrance channel.

A notable departure from these principles is the recently proposed extension, concave to windward, of the jetty at the mouth of the Columbia River. There is a local reason why the existing jetty at that place was built concave.

3.—It is advantageous to direct the ebb current into the littoral current tangentially or at a small angle. This was referred to under the heading "Groynes and Jetties."

4.—It is absolutely necessary to carry the jetty out to a depth in which the waves are powerless to stir up the bottom.

5.—After the weather angle has filled up, "the direction given by the convex form of the outer end of the jetty will carry the drift beyond the entrance and into the deep-water currents." This, also, was referred to under the heading "Groynes and Jetties."

It may be interesting to investigate to what extent this opinion is shared by other writers and borne out by experience.

Of Malamocco, Vernon-Harcourt says:

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* "If he had seen the results of a single jetty properly located, at the Malamocco entrance to the Harbor of Venice. . . ." p. 532.

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"The checking of the littoral current has reduced the depths on the northern side; but this diminution does not extend beyond depths of between 16 and 20 ft., so it has not hitherto affected the pass"

He also says:

"It is true that at all these places (Sunderland, Ymuiden, Dublin, Charleston), an advance of the shore has occurred; but its progress seems to have ceased at Ymuiden and Sunderland, it is very gradual at Dublin, and will probably prove equally so in other instances. Even at Port Said, which it was feared might be imperilled by the alluvial drift from the delta of the Nile, and which is undoubtedly exposed to a turbid current from the west, the advance of the western foreshore has become very slight."

The following is taken from Shield's "Principles and Practice of Harbor Construction," page 285:

"They (the waves) also heap up drift materials against obstacles, such as piers, etc., which run across the shore along which the drift travels; but when such piers extend into deep water, a considerable time often elapses before the drift material—as distinguished from that held in suspension—finds its way into the harbor, because the corners which the piers form with the coast constitute traps for it. As, however, these fill up, an advance of the foreshore takes place, and the material finds its way out to and round the pier-heads. Should these occupy a salient position, and extend well into the tide-way (for our harbors, read 'littoral storm current') the current past them will scour much of this away, and enable the depth of water at the entrance to be more easily maintained than under other conditions. Nevertheless, a current in passing an entrance often expands into the harbor and creates eddies, by means of which some of the drift material is almost sure to be carried in, and deposited under the lee of the piers. Total immunity from dredging can therefore scarcely be expected.

"In order to combat the advance of foreshores, jetties are often extended seaward; but such prolongations, unaided by dredging, are generally found to be of little permanent benefit, inasmuch as each extension of the pier causes a corresponding advance of the shore. The rate of such advance depends upon the physical conditions peculiar to each site, and especially upon the quantity of sand in motion. This varies greatly in different localities—hence, while the extensions of the jetties at such ports as Calais and Dunkirk have failed to produce the desired results, the prolongation of those at Port Said has been more successful; so much so, indeed, that it has been estimated it will take three centuries for the foreshore at Port Said to advance to the end of the piers, assuming its present rate of accumulation to be maintained.

"In order to keep open the Ymuiden harbor, it has been found necessary to dredge, on an average, about 650 000 cu. yds. of sand per annum, at an average cost of about £22 000.

"Such an expenditure as this can only be met by a very large traffic, and there can be no doubt that, but for this, Ymuiden harbor would ere now have ranked amongst the failures of harbors on sandy coasts."*

Wheeler illustrates his opinion by the following, relating to Lowestoft:

"Where it is contemplated to run out jetties into the sea at the

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* This deposit is of mud, and is brought into the harbor by the flood tide, and not by an advance of the foreshore around the jetty ends. There is no outer bar.

Mr. McKinstry. mouth of a tidal river in order to remove a shoal or bar, the risk of the gradual growth of the shore-line seawards until it progresses as far out as the pier has to be considered. Thus for the protection of the harbour of Lowestoft, situated on the flat shore of the East Coast, piers were built out from the shore-line. The windward pier, or that on the side from which the drift came, acted as a groyne, causing the sand and shingle to accumulate at the back and to extend a considerable distance out from the shore. * * * The shingle is constantly working its way round the end of the north pier into the harbour, necessitating constant dredging to maintain the depth. In north-east gales a bar also forms across the entrance, interfering with the navigation. In this case the jetty does not extend sufficiently far out to prevent the shingle travelling round the end, or to make the velocity of the littoral current sufficient to carry it past the pier-heads. The accumulation of shingle having now extended out from the shore past the piers, there is always at hand a constant supply of material for the littoral current to carry into the harbour. This could be prevented by arresting the travel of the shingle by a groyne carried out from the Ness, which projects from the coast-line about three-quarters of a mile to the north of the harbour entrance, and which could be extended from time to time as the material accumulated at the back."

To sum up: A windward jetty, especially a concave windward jetty, may be expected not to cause a dangerous advance of the foreshore when conditions are favorable, *i. e.*, when the entrance is not in the bight of a shallow bay, when the jetty is built out into deep water and its end is swept by a strong cross-current.

For, "in such a case," to apply to our case what Vernon-Harcourt says of converging-breakwater harbors, "sand does not come in through the entrance, as waves do not stir up sand in deep water; the current round the extremity assists in maintaining the depth; and owing to the depth which the advancing foreshore has to fill up and the projection from the shore which it has to assume, it may take a long period in reaching the end of the breakwater opposed to the littoral drift, or previously attain a position of equilibrium."

In applying this or any other system to any given place, the possibility would naturally be kept in mind that a bar might form beyond the entrance; and the location of the jetty and the curve given to its outer end would be such as not to preclude its extension. On the other hand, modern dredging methods afford a less expensive means of maintaining entrance channels than do periodical jetty extensions. Moreover, as DeMay says, the actual removal by dredges of the deposits which form before entrances has shown them to be of much less volume than was formerly thought.

For example, to maintain, not to speak of producing, a 21-ft. channel at Charleston, would require the inner ends of both jetties to be built up to about high-water level, and both to be extended out to, and probably beyond, the crest of the bar—not the bar of to-day, but the bar in any more remote position that it might assume as a result of this jetty work. Even this might fail to produce the desired result. The interest on the cost of this work would be greater than the sum it

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is now costing to maintain the desired channel by dredging. By reason of these recent improvements in dredging, dredging alone may afford a cheaper method of improvement than jetty work alone or jetty work supplemented by dredging. This, for example, was the conclusion recently arrived at for Brunswick Bar.

In beginning work under any given system of jetty improvement, a channel of something like the required depth and width may or may not lie in the position selected for the final channel. If it does not, the amount of material to be moved to form the desired channel may be very large, and if it moves slowly seaward under the influence of the advancing jetties, it may form a bar. When once the jetties have been completed and the desired channel has been produced either by scour or dredging, it is expected that sand deposited in the channel by a combination of unfavorable circumstances will be picked up, on the return of normal circumstances, carried to sea and dispersed. Circumstances, however, may defeat this expectation, and make dredging necessary. But while the jetties are in process of construction, the effect of steadily adding to their height and of steadily lessening the distance between them, is to increase the current between them to one that is just strong enough to scour. (This assumes that the required channel is not formed by dredging, and that the flow through other channels is more or less throttled by the jetties.) The transporting power of the current between the jetties is, of course, very small, and its load will be deposited upon the slightest diminution of velocity, that is, will be deposited just beyond the jetty ends, wherever they happen to be at the moment. The ultimate result is that much of the sand that occupied the locus of the desired channel has been shifted from its original position to one just beyond the jetty ends, in their final position. The tendency for the material to deposit in prolongation of the channel will decrease as the jetties are extended, for the current past the jetty ends will increase as the jetties grow longer, and will deflect the sand-laden issuing current to leeward. The above possible cause of the formation of bars is independent of the system of jetty improvement adopted, and indicates that in many cases it may be advisable to dredge while the jetties are advancing. There is no doubt in the writer's mind that the present bars at Charleston and at the St. Johns were largely formed in this way, for at both places the quantity of sand scoured out to form the present channels was enormous, and the depth beyond the jetty ends comparatively slight. Doubtless, however, in both cases, considerable of the sand in the present bars came in over the low places in the weather jetties.

To digress a moment, one cannot fail to notice, in the strictures passed on the Charleston improvement, a lack of fairness, or at least an absence of broad-minded consideration of the peculiarly unfavorable conditions surrounding that work. The place possesses about

Mr. McKinstry. every drawback that can be mentioned: It is situated in the bight of a bay, the rise and fall of the tide is not great, the quantity of sand moving along the coast is enormous, the water off the entrance is shoal, and the slope of the ocean floor is very flat. The improvement was begun more than 25 years ago, the yearly appropriations for it have been less than 5% of the total estimated cost, and time enough has elapsed to show the effect of the work done. What a magnificent field for a display of "hindsight"!

Compare the conditions as to depth at Coos Bay and at Charleston. At the former place, when the improvement was begun, there was a depth of 35 ft. at the distance of 1 mile from the harbor throat; at Charleston this depth was found 8 miles off the entrance. Again, where the Coos Bay jetty now ends there was a depth of 31 ft., and the channel depth to be obtained was 20 ft.; at Charleston, where the jetties now end there was a depth of only 18 ft., while 21 ft. was the channel depth desired. The above-mentioned unfavorable conditions; leaving a long, low place in the weather jetty close to its inner end, and not resorting earlier to dredging, are the causes of the present outer bar at Charleston—a bar which the current issuing from between the present jetties is powerless to scour. The success of the improvement is due to the work of sea-going suction dredges.

The "reaction breakwater" of Professor Haupt is a particular case of the single windward jetty, being a high windward jetty, detached from the shore and having a trace which is a "compound and reverse" curve.

Professor Haupt wishes a clear distinction made between the reaction breakwater and any single jetty rooted to the shore; for he says*:

> "Again, it is attempted to compare a single jetty projecting from the shore with the reaction breakwater which is purposely wholly detached therefrom."

Detachment from the shore, and the fact that the inner portion of the reaction breakwater is convex to the channel, are the two points of difference between that structure and the Brookes concave windward jetty. But the inner ends of many weather jetties in this country are convex to the channel: Witness, Charleston, Cumberland Sound and the St. Johns; and many of our jetties are detached jetties, or, what is the same thing, have the crests of their shore ends below low water—often well below that level.

The expressed object of placing the reaction breakwater to windward of the entrance is "to arrest the littoral drift"; but to leave a gap is to fail to arrest the drift at and near the shore where the amount of drift is greatest. At Port Said, as above mentioned, provision is made to remove, by dredging, the drift that comes in through the openings made in the weather breakwater; but dredging forms no part of the reaction breakwater system. The object of the gap is "to admit the

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* *Transactions*, Am. Soc. C. E., Vol. xlii, p. 530.

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full tidal prism." General Gillmore states that in a certain "flood" channel at Cumberland Sound—a channel close to the beach on the north side of the entrance—the gauged flow on the flood was about double that on the ebb. Leaving gaps is undoubtedly a means of increasing the preponderance of the ebb over the flood in the main channel, provided this channel is not too long. At Cumberland Sound and at the St. Johns this effect is assisted by the fact that the ebb current does not begin to run until after the tide has fallen about one-quarter of its range, and continues running until the water has risen about the same amount. But it may fairly be doubted whether the advantage accruing from a long, deep gap would offset the evil effect of offering a capacious opening to the drift, or whether a gap that would keep out drift except at highest water would materially increase the ebb's preponderance. Attempts have been made, as at the Adour and at Dunkirk, to solve the problem by "movable" jetties, that is, jetties which can be opened during flood tide (not, however, during storms), and closed during the ebb.

The object of the reaction breakwater's "compound and reverse curve" trace is stated to be to "produce reactions similar to those found in the concavities of streams." But this reason evidently cannot apply to the convex inner part of that structure. There is an excellent reason, to the writer's mind, why the inner part of the Aransas Pass jetty should be convex to the channel: In military parlance, it was necessary to refuse this flank to prevent its being turned. If it had not been given this shape there would have been little to prevent the channel from breaking out to the north of the jetty during a southwest storm. Similarly, half a dozen harbors can be named, at which, if an attempt should be made to lay down a Brookes' concave windward jetty, the main portion of the jetty would have to be connected with the shore by means of a convex portion, or a portion making an angle, measured on the channel side, of more than 180° with the main portion The reason of this is that the weather shore of the entrance is usually farther from the axis of the channel than the jetty should be. Coos Bay might be an exception. The Southwest Pass is another exception, and Professor Haupt's plan for this place omits the convex curve. While there are no novel elements in the reaction breakwater, the combination of these elements is unique, and the reaction breakwater at Aransas Pass is the first concave windward jetty built at a tidal entrance in this country.*

The foregoing discussion indicates, generally, that when it is proposed to rely upon a windward jetty as the main means of improvement at a place where the resultant drift is considerable:

1.—The outer end of the jetty should be concave to the channel.

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* This is taking for granted that the east side of the entrance is the windward side, which is disputed. If the west side is the windward side, then the original Government jetty was the first concave windward jetty built in this country.

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2.—The jetty should be connected with the shore, or, if a gap be left, provision must be made for dredging. In the general case it will be found necessary to make this connection by means of a curve convex to the channel.

3.—The jetty should be built up at least to high-water level, and should extend across the bar into deep water.

4.—In all cases except where the lee side of the entrance happens to be of the proper shape to direct the current into the concavity of the main jetty, a lee directing jetty, shorter than the main jetty, will be required. Where there is a strong resultant drift, the lee jetty need not be raised above the level of the beginning of ebb outflow.

The Single Lee Jetty.—Single lee jetties have been built straight, as at Coos Bay,* or convex to the channel, as at Grays Harbor.

All that has been said herein as to the advantage of directing the issuing ebb current into the littoral current with a minimum of disturbance, applies with equal force to the lee-jetty system. It is accomplished by making the jetty incline to leeward, or by making its outer end convex to the channel. As between a straight and a convex lee jetty, the advantage seems to lie with the latter.

The theory of the single lee jetty is this: Due to the prevailing storm winds and to the deposit of sand on the windward side of the issuing harbor current,† the channel is forced steadily to the leeward until it runs nearly parallel to the coast. Finally, its length and the friction of its bed become so great that on some favorable occasion, say during a strong off-shore blow following an on-shore storm and extreme high water, it breaks straight out through the bar, and its slow movement begins anew. A jetty built to leeward of the channel when the latter occupies, or lies to windward of, some favorable position, will intercept this steady movement to leeward; and, the pressure to leeward still continuing, the inflowing and outflowing waters confined against the jetty will scour a channel of the required depth in the selected location. The theory of the single lee jetty is set forth in various papers and discussions contributed to the *Transactions* of this Society by Major Symons.

The contention of the opponents of this system is that it tends to cause the formation of a bar about the entrance, beyond the jetty end. It may be interesting to inquire into this matter. As before stated, a jetty built out on a sandy coast invariably causes a deposit of sand on its windward side. When the jetty is located on the lee side of an entrance, the tendency to fill on its windward side,

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* The jetty at Coos Bay is on the lee side of the entrance, considering the direction of the prevailing storm winds. Whether it is on the opposite side to that from which the maximum drift comes is not so certain. It is the opinion of one who has long been connected with Pacific Coast works that the resultant drift at this place is from north to south, on account of the fact that the irregularities in the shore line to the south interfere with the movement of sand from that direction, while there is nothing to obstruct the sand movement from the north.

† This subject is well discussed and illustrated in Shield's "Principles and Practice of Harbor Construction," page 151.

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i. e., in the entrance, still exists, but is interfered with and prevented by the flow of the waters that make in and out of the harbor. What becomes of the sand that otherwise would be deposited in the windward angle of the jetty?

During storms from the prevailing direction, and while the flood current runs, the drift will be carried into the channel and the inner harbor; when the tide turns, the issuing current will deflect the drift-laden littoral current out to the end of the jetty. There the resistance to leeward movement ceases, and the united currents bend to leeward around the jetty end. All or nearly all of the sand that is carried into the inner harbor during the flood tide must be carried out again by the ebb current, otherwise the harbor would fill up. The issuing harbor current is therefore sand-laden, and joins its drift to that of the deflected littoral current. If the jetty is made long enough, this material will probably be dissipated in deep water.

The effect is the same in kind, if not in degree, when a low or detached weather jetty is used in connection with a high lee jetty. The efficacy of the weather jetty, in keeping the drift out of the channel and causing it to deposit on its windward side, depends upon the height and continuity of the jetty.

The tendency for a deposit to form along the windward side of the issuing ebb current, previously referred to, must be considered further. The same forces are at work here that act to cause an advance of the foreshore of the windward side of a groyne. During the flood the deposits on the windward side of the channel would suffer erosion, the eroded material being carried toward the inner harbor. The building up of shoals in the apex of the angle between the channel and the shore and along the windward side of the channel ought, therefore, to be slower than the corresponding deposit in the windward angle of a groyne or of a windward jetty, and such shoals would probably never rise to low-water level. Furthermore analogy indicates that if the jetty be made long enough and be carried into deep enough water the deposit ought not to overlap the entrance.

The formation of the south shoal at Coos Bay, however, looks like an instance of this overlapping. This shoal extends along the weather side of the channel, and at the outer end bends around parallel to what is probably the direction of the ebb current when deflected by the littoral storm current from the south. At a point in prolongation of the jetty, and about 1 200 ft. beyond its end, this shoal carries less than 18 ft. of water, where in 1885 there were more than 40 ft. A similar shoal formed in prolongation of the north jetty at the St. Johns, at one stage of the work, viz., after the south jetty had been built out considerably beyond the north. The overlapping shoal at Coos Bay is referred, by one commentator, to the jetty being on what he considers the wrong side of the entrance; but it may be due to the jetty not

Mr. McKinstry. having been built out far enough. It is by no means certain that a windward jetty, built out no further, would not produce a shoal equally bad.

In stating that the single windward jetty should be concave to the channel (and hence convex to windward), and that the single lee jetty should be convex to the channel (and hence convex to windward) convex and concave to windward refer to the prevailing storm winds; and a preponderance of drift from that direction is assumed. When, under the influence of winds from certain other directions, littoral current and drift are in the direction opposite to the prevailing direction, certain of the advantages of the concave windward jetty are exchanged for disadvantages; thus, the ebb current is discharged into the littoral current up stream instead of down stream, an easy passage of the deflected littoral current around the jetty end is prevented, and the disturbance caused by the meeting of the currents is increased. Because, however, it is impossible for a single jetty to suit these opposite conditions, it is best to give it such a shape as best suits the storm conditions, especially if the preponderance of current and drift from the storm direction is considerable. Similarly, in the case of the single lee jetty, when littoral current and drift are opposed to the prevailing direction the "pressure to leeward" does not exist and there is nothing except the shape of the banks to hold the inflowing and outflowing currents to the channel. Here again, however, the storm conditions, being the more powerful, are the conditions to be accommodated.

At places where there is no preponderance of drift, the conditions must be met by two converging jetties, extending out to the same contour of depth, each part making a large obtuse angle with the shore.

In any case it should be noted that the trending of the ebb current to leeward under the influence of the littoral current flowing across the entrance—inducing a dissipation of material or a deposit elsewhere than in prolongation of the channel—may be prevented by a sudden change of wind.

From the point of view of ease and safety of navigation, the windward jetty is superior to the lee. The former stills the sea at the entrance—a matter of importance, because, in a heavy sea, the available depth is decreased by the drop of the waves as well as by the resulting "send" of the vessel. Thus, at the mouth of the Columbia River, a depth of 40 ft. is considered advisable for vessels that require but 30 ft. in still water.

Similarly, in the case of two jetties, an overlapping weather jetty will give some protection to entering vessels before they come abreast of the end of the lee jetty.

A single lee jetty is a "lee shore," and makes a dangerous sea. Note, again, however, that the terms "windward jetty" and "lee jetty," as here used, apply only during storms from the prevailing direction. The designations change under certain changes of wind. Mr. McKinstry.

Physical and nautical requirements are in opposition in the case of entrances formed by the two sorts of jetties under consideration, and neither jetty gives an entrance facing in the most favorable direction for sailing vessels that may try to make the harbor during a storm from the prevailing direction. But this is not so important in these days when sailing vessels have been largely superseded by steam, and when coasting sailing vessels receive timely warning of the approach of storms.

The writer expresses the opinion—necessarily, under the circumstances, a merely academic opinion—that the concave windward jetty, supplemented by a lee jetty sufficiently long to direct the ebb current properly, is preferable to the single lee jetty.

In conclusion, a word on the text: "The sea seems almost to take a delight in thwarting a timorous or vacillating policy.* A well-thought-out plan having once been adopted, vigor and steadfastness should characterize its execution. Often, to be sure, irregular and insufficient appropriations, and the impossibility of doing anything that will temporarily decrease an existing navigable depth, no matter how beneficial the ultimate result may be, have prevented such a course on many of the works in this country. To build a windward jetty to low water in the hope that it may not be necessary to build it to high water; to leave a gap in a windward jetty for fear the tidal prism may be reduced, when, if necessary, dredging should be resorted to, to prevent this reduction; to build a jetty out to a certain point and then await results in the hope that a shorter jetty than the one originally planned may accomplish the end desired: These are methods of inviting an advance of the bar and greatly increased final expense.

Mr. Harts. **William W. Harts**, M. Am. Soc. C. E. (by letter).—The writer is well pleased with the discussion aroused by this paper, and the attention to the subject that has been apparently drawn by it.

Professor Haupt's discussion seems mainly to show a careful endeavor to explain away definite results achieved, and to defend the peculiar theory of erosion by "impact" or "reaction."

Stevenson's formula, referred to as showing the relation between wave height and fetch, was inserted in the paper merely to show that such a relationship was well recognized, but the formula was purposely not applied specifically to this locality.

There seems to be some confusion in Professor Haupt's use of the terms "windward" and "leeward" sides of the channel. It is possible that the sides of the channel from which come the worst and longest storms, and that from which the resultant sand movement comes, may not be the same. This appears to be the case at Coos Bay. It is not

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* *Transactions*, Am. Soc. C. E., Vol. xxx, p. 499.

Mr. Harts. plain in such cases which side would answer the "rule of thumb" of "one jetty to the windward." Attention might properly be called to the danger of the indiscriminate application of rules of this character to cases which may and usually do differ as much as the various ocean ports of the United States, unless a careful study of the natural conditions of the place considered is also made.

The fact of the unusual depths of 30 ft. or more at mean lower low water, found across the bar at Coos Bay before improvement, during the occasional and short periods when the channel in its cyclic change of position went westward straight to sea, shows the possibilities of improvement at this place. In approximating to these possibilities, may not a practically permanent increase in the usual or ruling depth of more than double what it was originally, thus satisfying both the terms of the project and the present requirements of navigation, be termed a distinct success?

Also, it is not admitted by all engineers that there is any positive evidence in fact for the theory of erosion by "impact" of water particles in running streams. The well-known theory of the relation between bottom velocity and erosive and transporting powers still has its advocates.

Professor Haupt refers to the Second Board of Engineers, called to report upon the further improvement of Yaquina Bay, just after the completion of the first project. Attention might also have been called to the fact that, the first project having been satisfactorily completed, this Board was presumably called, more for political reasons than otherwise, to advise the Secretary of War as to the feasibility of methods of still further increasing the depths already secured.

In 1900, still another Board recommended that no further jetty work be done, depths being ample for all present needs. There has been for years an available channel of seldom less than 15 ft. depth at mean lower low water, and frequently of something more. The survey of 1900 was made after a period of very severe southwest storms, and although the best depths at the bar at that time, stated by Professor Haupt to be 8 or 10 ft., were actually 13 ft., it may be added that after a short period of smooth weather, this depth was again increased to the usual 15 ft., and about a month later to 16 ft.

It is the writer's belief that no form of improvement will prevent the occasional heaping up of sand in the channels of improved harbors on the Pacific Coast during severe storms, but that, with works properly designed and maintained, the concentrated current will invariably cause the channel to resume its usual depth when quiet weather prevails. It seems impossible to fix absolutely, on this coast, the balance between the shoaling effect of the sea in storms, on the one hand, and the scouring effect of the tidal flow, on the other.

Professor Haupt's reference to the improvement of the bar of the harbor at Brunswick, Ga., by dynamite, seems particularly unfortunate, in view of the recent information* published by the War Department, concerning this port. Mr. Harts.

In this comprehensive and convincing report, made by Captain Gillette, Corps of Engineers, U. S. A., on the improvement of this harbor, the following appears in reference to the cost of ordinary dredging, etc.:

> "This table shows the remarkable fact that up to 1897 (six years) the total result of work in the vicinity of the Goodyear channel was a fill instead of a scour. This was the period in which dynamite alone was used to do the work, aided only by harrows, rakes, and a dredge without bins, but not by ordinary hydraulic dredging. * * * The results for the total period from 1891 to 1898 are also quite meager—a maximum of 218 260 cu. yds., considering a width of 800 ft., 400 ft. each side of the axis of the present channel. For this there has been paid Mr. Goodyear $220 000, and the numerous surveys to determine the results of his work have cost $26 989.83, making a total of $246 989.83, or at the rate of $1.13 per cubic yard, assuming that the removal over this wide area was all useful, and that it was all done by Mr. Goodyear. * * * Fifteen cents per cubic yard is a fair price for this work. The contractor now working at Doboy Bar, the next bar north of Brunswick, and apparently of the same nature, gets 13.9 cents per yard, and he has had to build his dredge for this job. The price of 15 cents per yard may be objected to on the ground of 'tough blue clay' and 'sand, shells, and gravel cemented together.' The report of the original survey of 1891 states 'sand and blue mud,' the latter when under water being 'soft and very easily eroded.' It is to be noted, too, that Mr. Bryan, the dredging contractor who did the dredging for Mr. Goodyear, while arguing that 15 cents is too small, gives the reasons of 'distance from land' and the 'weather conditions,' but says not a word about tough materials (p. 54). The other two conditions are about the same at Doboy as at Brunswick. At 15 cents the entire work would have cost $18 750, a little over two-thirds the amount it has cost the Government for making the surveys to see what Mr. Goodyear had accomplished."

The conclusions drawn in regard to deepening by dynamite at this place are as follows:

> "*First.*—Dynamite does not have any useful effect in bar deepening, except in loosening tough materials in the immediate vicinity of explosions. Such materials are very rare on bars along sandy coasts.
>
> "*Second.*—The channel now existing at Brunswick Bar has been produced by nature, aided very materially by ordinary dredging. The useful effect of dynamite has been very small, except, possibly, to loosen materials in some places as an aid to the dredge.
>
> "*Third.*—The cost to the Government of all material removed, whether usefully removed or otherwise, has been $1.13 a yard, more than seven times the cost of ordinary dredging. The cost to the contractor is said to have been even more than this.
>
> "*Fourth.*—The channel produced has no advantage of permanence over a dredged channel of similar size and location, which could be produced for about one-twelfth of the cost of the present channel."

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* H. Doc. 355, 56th Cong., 2d Sess.

Mr. Harts. Major Black's experience and views corroborate those of the writer, with regard to the use of two jetties in similar harbor improvement, and that the effect of a single jetty is but partial. He is believed to be right in his presumption, that the resultant sand movement, at this point, is from the north, in spite of the fact that the worst and longest storms come from the south and southwest.

Mr. Ripley, in his discussion, fails to grasp the fact before stated, that the resultant sand movement and the worst weather apparently come from different directions.

Would it not be evidently inadvisable, in such a case as this, to endeavor to control sand movement from the north by a jetty on the south ?

It is believed that Mr. Ripley's understanding of the description of this work must be considerably in error, for his reference to a "fluctuation of as much as 13 ft." intimates that no reliance by mariners is to be placed on the depths secured. The writer regrets exceedingly if his description conveys such a misapprehension to unprejudiced minds.

As to whether the results achieved at this place were originally produced and are still controlled by the jetty, or whether they are at the caprice of the wind and wave, may be safely left to the unbiased judgment of the reader, as well as the question of how well this work answers the conditions to be filled, before improvement may be expected.

The writer has visited the harbor of Venice, and has studied the effect of the Malamocco jetty work. He has also read a number of the valuable writings of Professor Haupt, and is still of the opinion that if the south jetty at Coos Bay had been built first, no valuable result would have been secured in concentrating the tidal flow over the bar, and in controlling the serious sand movement on the north side of the entrance; and that such work, if built as recommended by Professor Haupt and Mr. Ripley, would be practically valueless for the benefit of navigation, until a north jetty could be built to fulfill the functions now performed by the north jetty. This would have delayed for a number of years the valuable results already achieved.